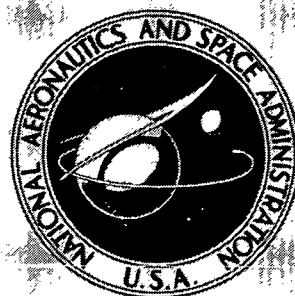


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**CESIUM-DIODE PERFORMANCES
FROM THE 1963-TO-1971
THERMIONIC CONVERSION
SPECIALIST CONFERENCES**

by James F. Morris

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Cleveland, Ohio 44135*

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1972

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CESIUM-DIODE PERFORMANCES FROM THE 1963-TO-1971 THERMIONIC CONVERSION SPECIALIST CONFERENCES

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SUMMARY

This report indexes and summarizes papers containing cesium-diode results from the proceedings of the 1963-to-1971 Thermionic Conversion Specialist Conferences. Lists of converter materials, geometries, conditions, outputs, and lifetimes accompany the references. Simple chemical designations for emitters, collectors, and additives direct the reader to appropriate selections.

INTRODUCTION

Most cesium-diode performance studies reach the Thermionic Conversion Specialist Conferences eventually. If the work fails to appear in the proceedings originally, it often enters in subsequent comparisons. And the accompanying references generally include expansive current, voltage data in agency, contractor, or company publications. So the Thermionic Conversion Specialist Conferences provide extensive cesium-diode output information. To increase the accessibility of this technology the present report indexes and summarizes such contributions for the past decade.

Beginning with the 1963 conference an annotated, chronological tabulation indicates 129 papers containing thermionic-converter results. Lists of diode materials, geometries, conditions, outputs, and lifetimes, if they were found, accompany the references. A simple chemical index for emitters, collectors, and additives directs the reader to appropriate selections. Because these chemical labels are guides not analyses, they lack the complexity of additive product permutations; they are easily recognized elemental or molecular forms. But they adequately identify the materials involved.

With a set of the proceedings for the Thermionic Conversion Specialist Conferences and the present report, comprehensive literature surveys on cesium-diode performances are readily available.

SIMPLE CHEMICAL INDEX FOR DIODE MATERIALS

Emitter	Reference
Cavity	53
Iridium (Ir)	10, 17, 18
Molybdenum (Mo)	5, 6, 7, 9, 10, 12, 14, 20, 21, 34, 38, 39, 47, 82, 84, 89, 92, 98, 100 (single-crystal 110 (1-xtal 110)), 120, 127,
Molybdenum-based alloy	98
Rhenium (Re)	3, 4, 12, 14, 15, 16, 19, 21, 22, 23, 27, 31 (electroetched), 40, 41, 42, 44, 56 (etched), 57 (etched), 58 (electro-etched), 59, 64, 65, 66, 67, 68, 69, 73, 74, 76, 79 (1-xtal 0001), 82, 87, 91, 95, 101, 103, 107 (etched), 114 (etched or 1-xtal 0001), 115 (chemically vapor-deposited (CVD)), 122 (etched), 125 (etched), 126
Ruthenium (Ru)	11, 45
Tantalum (Ta)	4, 5, 42, 46, 53, 66, 82
Tungsten (W)	2, 4, 8, 13, 14, 21, 22, 24, 25, 26, 28, 29, 30 (Cl ⁻ CVD, 110), 33, 37, 43 (Cl ⁻ CVD), 48 (F ⁻ CVD (100) etched to 110), 49 (Cl ⁻ CVD), 50 (Cl ⁻ CVD, F ⁻ CVD), 55 (VD), 60, 61, 62 (1-xtal 110), 63, 70 (Cl ⁻ CVD, F ⁻ CVD), 71 (Cl ⁻ CVD), 72 (F ⁻ CVD, four surface preparations), 80 (F ⁻ CVD etched to 110), 81 (1-xtal 110), 82 (several orientations and surface preparations), 83 (1-xtal 110), 84 (F ⁻ CVD), 85 (F ⁻ CVD), 86 (Cl ⁻ CVD), 88 (F ⁻ CVD), 90 (F ⁻ CVD), 90 (F ⁻ CVD, four surface preparations), 93 (SIMCON), 94 (Cl ⁻ CVD), 96 (CVD), 97 (physically vapor-deposited (PVD)), 102 (1-xtal 110, Cl ⁻ CVD, F ⁻ CVD), 104 (1-xtal 110, Cl ⁻ CVD, F ⁻ CVD), 105 (1-xtal 110, Cl ⁻ CVD, F ⁻ CVD), 106 (F ⁻ CVD etched to 110, Cl ⁻ CVD, F ⁻ CVD), 108 (Cl ⁻ CVD), 109 (Cl ⁻ CVD, F ⁻ CVD), 110, 111, 112, 113 (F ⁻ CVD), 116 (CVD), 117 (Cl ⁻ CVD), 118 (F ⁻ CVD), 121 (Cl ⁻ vapor deposited by thermal decomposition (TVD)), 122 (PVD, Cl ⁻ CVD), 123 (Cl ⁻ CVD), 124 (PVD, Cl ⁻ CVD, F ⁻ CVD), 126, 128 (CVD), 129 (Cl ⁻ CVD, SIMCON)

Emitter	Reference
Tungsten-based mixture	98 ('tungsten-based alloy,' 'tungsten, rhenium'), 32 (W, 20 percent Re), 78 (W, 25 percent Re), 82 (W, 25 percent Re), 1 (with a small amount of Th), 119 (W, 2 percent ThO ₂)
Collector	Reference
Grooved	36
Inconel	8
Molybdenum (Mo)	3, 4, 5, 11, 12, 13, 15, 19, 22, 24, 27, 30, 31, 33, 34, 36 (with and without grooves), 38, 39, 40, 41, 42, 44, 45, 49, 50, 51, 53, 56, 57 (VD), 59, 62, 63, 64, 69, 71, 74, 76, 82, 84, 89, 91, 92, 93 (SIMCON), 94, 95, 96, 99, 100 (1-xtal 110), 104, 105 (polycrystal (polyxtal) or PVD (110)), 108 (PVD), 110, 113, 114, 116, 118, 120, 122, 123 (PVD), 124 (PVD), 125 (PVD), 128
Nickel (Ni)	2, 7, 9, 10, 14, 16, 20, 21, 25, 28, 29, 33, 37, 43, 46, 51, 60, 82, 121
Niobium (Nb)	6, 21, 29, 45, 47, 48, 50, 56, 58, 66, 67, 68, 69, 70, 72, 79, 80, 81, 82, 85, 86, 90, 97, 98, 99, 101, 102, 103, 104, 105, 106, 107, 109, 112, 117, 121, 122, 123, 126, 129
Niobium-based mixtures	45 (Nb, 0), 55 (Nb, 1 percent Zr), 84 (Nb, 1 percent Zr), 88 (Nb, 1 percent Zr), 115 (Nb, 1 percent Zr), 127 (Nb, 1 percent Zr)
Palladium (Pd)	58
Rhenium (Re)	40, 45, 58, 65, 82, 87 (Cl ⁻ CVD), 91
Ruthenium (Ru)	11, 45
Silver (Ag)	23
Stainless steel	1, 17, 18 (304)
Tantalum (Ta)	4, 5, 26, 111
Tungsten (W)	25 (from emitter on Ni collector), 61, 83 (1-xtal 110), 121, 123 (1-xtal 110, polycrystalline)
Tungsten-based mixtures	78 (W, 25 percent Re), 82 (W + WO ₂ on Nb collector)

Additive	Reference
Argon (Ar)	35, 46, 75
Barium (Ba)	13, 111, 120
Carbon (C) (possible diffusion into diode from UC)	3, 6, 117
Cesium fluoride (CsF)	12, 24, 34
Cesium oxide (Cs ₂ O)	44, 52
Fluorine (F or F ₂)	12, 24, 34
Hydrogen (H or H ₂)	2, 14
Iodine (I or I ₂)	46
Krypton (Kr)	46, 54
Nitrogen (N or N ₂) (possible diffusion into diode from UN)	126
Oxygen (O or O ₂)	7 (possible diffusion into diode from UO ₂), 8 (UO ₂), 9 (UO ₂), 23, 28 (UO ₂), 44, 45 (in Nb), 47 (UO ₂), 52, 55 (UO ₂), 88 (UO ₂), 89 (UO ₂), 104, 105, 112 (UO ₂), 114, 117 (UO ₂), 119 (from ThO ₂ in emitter), 124, 125 (UO ₂)
Thorium (Th) (from the emitter composition)	1 (in W), 119 (W, 2 percent ThO ₂)
Uranium (U) (possible diffusion into diodes from fuel)	3, 6, 7, 8, 9, 28, 47, 55, 88, 89, 112, 117, 125, 126
Xenon (Xe)	17, 18, 46, 54, 75

Emitter (E), Collector (C), Combination	Reference
Iridium (E)	
Stainless steel (C)	17, 18
Molybdenum (E)	
Molybdenum (C)	5, 12, 34, 38, 39, 82, 89, 92, 100, 120
Niobium, 1 percent zirconium (C)	127
Niobium (C)	6, 47, 98
Nickel (C)	7, 9, 10, 14, 20

Emitter (E), Collector (C), Combination	Reference
Molybdenum-based alloy (E)	
Niobium (C)	98
Rhenium (E)	
Molybdenum (C)	3, 4, 12, 15, 19, 22, 27, 31, 40, 41, 42, 44, 56, 57, 59, 64, 69, 74, 76, 82, 91, 95, 114, 122, 125
Nickel (C)	14, 16, 82
Niobium (C)	21, 56, 58, 66, 67, 68, 69, 79, 82, 101, 103, 107, 122, 126
Niobium, 1 percent zirconium	115
Palladium (C)	58
Rhenium (C)	40, 58, 65, 82, 87, 91
Silver (C)	23
Tantalum (C)	4
Ruthenium (E)	
Molybdenum (C)	11, 45
Niobium (C)	45
Niobium with oxygen (C)	45
Rhenium (C)	45
Ruthenium (C)	11, 45
Tantalum (E)	
Molybdenum (C)	4, 5, 42
Nickel (C)	46
Niobium (C)	66, 82
Tantalum (C)	4, 5
Tungsten (E)	
Inconel (C)	8
Molybdenum (C)	13, 22, 24, 30, 33, 49, 50, 62, 63, 71, 82, 84, 93, 94, 96, 104, 105, 108, 110, 113, 116, 118, 123, 124, 128
Nickel (C)	2, 14, 21, 25, 28, 29, 33, 37, 43, 60, 82, 121
Niobium (C)	21, 29, 48, 50, 70, 72, 80, 81, 82, 85, 86, 90, 97, 102, 104, 105, 106, 109, 112, 117, 121, 122, 123, 126, 129
Niobium, 1 percent zirconium (C)	55, 84, 88
Tantalum (C)	4, 26, 111

Emitter (E), Collector (C), Combination	Reference
Tungsten (C)	25, 61, 83, 121, 123
Tungsten and tungsten oxide on a niobium col- lector (C)	82
"Tungsten-based alloy" (E)	
Niobium (C)	98
Tungsten, rhenium alloys (E)	
Nickel (C)	82
Niobium (C)	98
Tungsten, 25 percent rhenium (C)	78
Tungsten with a small amount of thorium (E)	
Stainless steel (C)	1

CHRONOLOGICALLY ORDERED, ANNOTATED REFERENCES ON CESIUM-DIODE PERFORMANCES FROM THE 1963-TO-1971 PROCEEDINGS OF THE THERMIONIC SPECIALIST CONFERENCES

Report on the Thermionic Conversion Specialist Conference. IEEE, 1963.

1. Houston, John M.: Measurements of Emitter Heat Balance in a Cesium Thermionic Converter, pp. 214-223.

Emitter	W with a small amount of Th; $T_E = 1900$ to 2200 K
Collector	stainless steel; $T_C = 583$ to 783 K and optimum
Cesium gap	1 mm; $T_R = 424$ to 573 K
Additive	Th
Geometry	cylindric, 1.52-cm diameter, 13.3 cm^2
Output	0.4 to 0.8 W/cm^2 with 1.2 to 2.4 percent efficiency at 1900 K; 6 to 9 W/cm^2 with 8.8 to 12 percent efficiency at 2200 K

2. Rump, B. S.; Bryant, J. F.; and Gehman, B. L.: Study of the Influence of Additives on Work Function and Power Output of Thermionic Cells, pp. 236-239.

Emitter W; $T_E = 1000$ to 2300 K
 Collector Ni; $T_C = 400$ to 1000 K and optimum
 Cesium gap $T_R = 100^\circ$ and 200° C
 Additive H_2
 Geometry filamentary
 Output power for Cs alone above that for Cs + H_2 with $T_R = 100^\circ$ C; for $T_R = 200^\circ$ C power for Cs + H_2 above that for Cs alone at $T_E < 1900$ K; for $T_R = 200^\circ$ C power for Cs + H_2 at 1500 K equal to that for Cs alone at 2100 K; power range 10^{-6} to 10^{-1} W/cm²

3. Howard, Robert C.; Keller, D. L.; and Smith, C. K.: Converter Performance Test of a Rhenium Emitter in Contact with a Carbide Fuel, pp. 287-294.

Emitter Re (UC backed); $T_E = 1550^\circ$ C (129 hr), 1600° C (72 hr)
 Collector Mo; $T_C = 603^\circ$ to 617° C
 Additive U and C possible
 Geometry plane
 Output 5 W/cm² (0.5 V, 1550° C), more than 8 W/cm² (0.5 V, 1600° C), no degradation of performance
 Lifetime 201 hr; thermal bond separation in fuel, emitter sandwich

4. Merra, S. G.; and Weinstein, J. H.: Recent Progress in the Development of Solar Thermionic Converters, pp. 295-304.

Emitter Re, Ta, or W; $T_E = 1980$ to 2050 K
 Collector Mo or Ta; radiation cooled
 Cesium gap 0.051 to 0.064 mm; T_R optimized
 Geometry plane solar diodes
 Output as shown in the following table (from ref. 4):

SOLAR HARDWARE CONVERTERS (1962-1963)

Type	Date	Emit- ter	Col- lector	Emit- ter area, cm ²	Spac- ing, mm	Volts	Am- peres	Watts	Emit- ter tem- perature, K	Geom- etry	Num- ber built
Series VI	1962- 1963	Ta	Ta	2	0.064	0.8 1.0	28.0 18.7	22.4 18.7	2000 } 2000 }	Flat	21
VI-S-15	1962	Ta	Ta	2	0.064	0.6	71.0	42.6	2050	Flat	
EX-1, -7	1962	Re	Mo	2	0.058	0.7 1.0	50.0 13.2	35.0 13.2	1990 } 2040 }	Flat	2
EX-2, -3	1962	Re	Ta	2	0.058	0.7	30.0	21.0	1990	Flat	2
EX-4, -5, -6	1962	W	Ta	2	0.058	0.5 1.0	27.0 6.8	13.5 6.8	1980 } 1980 }	Flat	
EX-8	1962	Ta	Mo	2	0.064	0.7 1.0	25.5 11.0	19.0 11.0	2000 } 2000 }	Flat	1
EX-9	1962	Ta	Ta	2	0.064	0.6 1.0	40.0 12.0	24.0 12.0	2000 } 2000 }	Flat	1
Series VII	1963	Ta	Ta	2	0.051	0.5 1.0	40.0 12.0	20.0 12.0	2000 } 2000 }	Flat	9
Series 2	1962	Ta	Mo	3	0.051	1.0	20.0	20.0	2000	Flat	11
Series 300	1963	Ta	Mo	3	0.051	0.5	58.0	29.0	2000	Flat	5

Lifetime over 2000 hr

5. Rouklove, P.: Results of Laboratory Tests of Set Thermionic Converters and Generators, pp. 305-313.

Emitter Mo (C), Ta (A, B, D); $T_E = 1677^\circ \text{C}$ (D) and 1700°C (A, B, C)
Collector Mo (B, C, D), Ta (A); radiation cooled
Cesium gap 0.051 mm (A), 0.025 to 0.203 mm (B), 0.127 mm (B); T_R optimized
Geometry plane solar diodes
Output 11 to 18 W/cm² to 0.6 V with 8.5 to 9 percent efficiency (A), 5 to 8.5 W/cm² maximums for 0.076 to 0.025 mm at 0.6 V with 5.4 percent efficiency (B), 9.3 W/cm² maximum with 7.4 percent efficiency (B), 7.0 to 8.5 W/cm² (C), 10 to 13 W/cm² (D)
Lifetime some in excess of 2000 hr

6. Busse, C. A.; Caron, R.; and Salmi, Ernest W.: In-Pile Test of a Thermionic Converter, pp. 314-322.

Emitter	Mo ((UZr)C backed)
Collector	Nb
Cesium gap	0.5 mm
Additive	U and C (through the emitter and through a hole in the emitter)
Geometry	cylindric with emitter cavity, diode gap, and Cs reservoir interconnected
Output	0.22 W/cm ² at 1 MW reactor power ($T_R = 177^\circ \text{C}$)
Lifetime	cesium heater failed in initial checkouts and allowed no high-power runs in the reactor

7. Block, Fred G.; Eastman, G. Y.; and Harbaugh, Willis E.: The Design, Development, and In-Pile Testing of a Nuclear-Fueled Thermionic Energy Converter, pp. 323-331.

Emitter	Mo (UO ₂ backed); $T_E = 1200^\circ$ to 1700°C with 1350°C design optimum
Collector	Ni; T_C optimums 525° to 825°C (for 1200° to 1700°C); 570°C for $T_E = 1350^\circ \text{C}$
Cesium gap	0.838 to 0.076 mm optimums (for 1200° to 1700°C), 0.279 mm for $T_E = 1350^\circ \text{C}$; T_R optimums 270° to 380°C (for 1200° to 1700°C), 310°C for $T_E = 1350^\circ \text{C}$
Additive	U and O possible
Geometry	cylindric; 60 cm ²
Output	1.3 to 15 W/cm ² (for 1200° to 1700°C), 3.2 W/cm ² at $T_E = 1350^\circ \text{C}$; 11 percent "typical efficiency"; in-pile 2.25 W/cm ² at 9 percent efficiency (see ref. 9)
Lifetime	2600 hr for one and 1400 hr at 3 W/cm ² for another out of pile, both continuing; in-pile performance plummeted after 300 hr

8. Beckjord, Eric S.: Test Results on an In-Pile Nuclear Thermionic Converter, pp. 332-340.

Emitter	W (UO ₂ backed); $T_E = 1700^\circ$, 1720° , 1800°C
Collector	Inconel; $T_C = 650^\circ$ to 700°C
Cesium gap	0.254 mm; $T_R = 335^\circ$ to 345°C for power maximums
Additive	U and O possible
Geometry	cylindric; 1.17-cm diameter, 8.6 cm ²
Output	4 W/cm ² at 0.6 V and 1700°C , 5 W/cm ² at 0.64 V and 1720°C , 6 W/cm ² at 0.78 V and 1800°C ; 10.5 percent efficiency at peak 6.2 W/cm ² and 1800°C
Lifetime	224 hr in testing reactor before Cu pinchoff failed

9. Eastman, G. Y.; Basiulis, A.; and Harbaugh, W. E.: Thermionic Converter Operation in Multiple Connection, pp. 348-355.

Emitter Mo (UO_2 back); $T_E = 1300^\circ$ to 1500° C
Collector Ni; T_C optimized
Cesium gap optimized widths and T_R 's
Geometry cylindric, 60 cm^2
Output 1 to 4 W/cm^2 at 8 to 12 percent efficiencies (see ref. 7); complete performance map

10. Martini, W. R.: Internal Flame-Heated Thermionic Converters, pp. 356-361.

Emitter Ir at 1430° C, Mo at 1400° C
Collector Ni
Cesium gap 0.762 mm with $T_R = 252^\circ$ C for Ir, 0.208 mm with $T_R = 315^\circ$ C for Mo
Geometry plane; 2.54-cm diameter
Output projected from RCA tube 1195A data, 5.5 W/cm^2 for Ir, 4.25 W/cm^2 for Mo

Report on the Thermionic Conversion Specialist Conference. IEEE, 1964.

11. Kennedy, A. J.; and Trimmer, D. S.: The Performance of Ruthenium as an Electrode in a Thermionic Converter, pp. 63-70.

Emitter two of hot-pressed Ru, one of plasma-sprayed Ru; $T_E = 1500$ to 1900 K
Collector one of arc-cast Mo, two of plasma-sprayed Ru; $T_C = 698$ to 1031 K
Cesium gap 0.102 to 0.762 mm; $T_R = 535$ to 589 K
Geometry plane
Output 8 W/cm^2 for 0.254 mm and $T_E = 1800$ K; Ru gives higher power densities than Re and Ir produce for gaps wider than 0.254 mm

12. Jester, Alfred A.: The Influence of a Cesium Fluoride Additive on the Power Output of Cesium Diodes with Molybdenum and Rhenium Emitters, pp. 93-99.

Emitter (1) Mo or (2) Re; $T_E = 1800$ K (A), 1900 K (B), 2000 K (C)
Collector Mo; $T_C = 750$ or 800 K or optimum
Cesium gap 0.05 to 0.4 mm; $T_R = 531$ to 609 K or optimum
Additive CsF at $T_{\text{CsF}} = 800$ K
Geometry plane

Output for Cs with CsF: emitter (1A) 12 W/cm² at 0.35 V; (1B) 20 W/cm² at 0.5 V; (1C) 24 W/cm² at 0.6 V; (2A) 16 W/cm² at 0.4 V; (2B) 20 W/cm² at 0.65 V; (2C) 28 W/cm² at 0.7 V; at identical voltages Cs with CsF gave more power, allowed lower Cs pressure, or permitted greater gap widths; good performance maps

13. Psarouthakis, John: Thermionic Energy Converter with Barium and Cesium Vapors, pp. 100-109.

Emitter W; $T_E = 1700, 1800, 1900, \text{ or } 2000 \text{ K}$
 Collector Mo; T_C 's within 25° C above T_{Ba} 's
 Cesium gap 0.025 to 1.016 mm; $T_R = 425 \text{ to } 647 \text{ K}$
 Additive Ba; $T_{Ba} = 1000 \text{ to } 1200 \text{ K}$
 Geometry plane
 Output 8.5 W/cm² at $T_E = 2000 \text{ K}$, $T_C = 1100 \text{ K}$, $T_{Ba} = 1080 \text{ K}$, $T_{Cs} = 470 \text{ K}$ with a "fundamental conversion efficiency" of 27 percent; output dropped from 8.5 to 8.2 W/cm² as the gap widened from 0.051 to 1.016 mm

14. Hall, W. B.; and Shoemaker, R. E.: Control of Gas Impurities in a Thermionic Converter, pp. 110-114.

Emitter Mo, Re, or "special" W; $T_E = 1250^\circ \text{ to } 1550^\circ \text{ C}$
 Collector Ni; optimum T_C 's
 Cesium gap optimum width; optimum T_R 's
 Additive H₂
 Geometry plane; 11.7 cm²
 Output at 1550° C, 9.5 W/cm² (Mo), 12 W/cm² (Re), 17 W/cm² (W); H₂ from 10⁻⁶ to 10⁻³ torr did not affect W or Re; it dropped Mo performance 15 percent and lowered the output of a contaminated W emitter over 40 percent.

15. Shavit, Arthur; and Hatsopoulos, George N.: Operation of a Thermionic Converter for the Ion-Rich Unignited Mode, pp. 206-213.

Emitter Re; $T_E = 1520 \text{ to } 1900 \text{ K}$
 Collector Mo
 Cesium map 0.008 to 0.254 mm; $T_R = 480 \text{ to } 539 \text{ K}$
 Geometry plane, guarded
 Output very low (unignited mode)

16. Wilson, V. C.: Evidence for a Double Sheath Adjacent to the Emitter, pp. 285-290.

Emitter Re; $T_E = 1700$ to 2123 K
Collector Ni; $T_C = 873$ K
Cesium gap 0.051 mm; $T_R = 593$ to 643 K
Output 38 W/cm² at 0.5 V and 2000 K

17. Kaplan, C.: Pulsed-Discharge Experiments in a Thermionic Converter, pp. 326-332.

Emitter Ir; $T_E = 1370^\circ$ C
Collector stainless steel; $T_C = 290^\circ$ to 760° C
Cesium gap 0.310 mm; $T_R = 290^\circ$ C
Additive Xe; 60 torr
Geometry plane
Output postulate of higher performance with Xe because of increased Cs_2^+ decay times

18. Kaplan, C.; and Merzenich, J. B.: Xenon Addition Experiment in a Thermionic Converter, pp. 333-344.

Emitter Ir; $T_E = 1260^\circ$ to 1370° C
Collector 304 stainless steel; $T_C = 607^\circ$ to 682° C and $1.62 T_R$
Cesium gap 0.178 to 0.762 mm; $T_R = 270^\circ$ to 310° C
Additive Xe; 60 torr
Geometry plane
Output 8.3 W/cm² maximum for Cs + Xe with $T_E = 1370^\circ$ C; Xe increased output 15 to 80 percent; Ne decreased output; performance curves

19. Merra, S.: Test Results of Solar Thermionic Converters Using Rhenium Emitters, pp. 350-359.

Emitter Re pyrolytic or pressure-bonded, $T_E = 2000^\circ$ C
Collector Mo, $T_C = 529^\circ$ to 821° C
Cesium gap 0.051 mm, $T_R = 336^\circ$ to 398° C
Geometry plane solar diode, 2.0 cm²
Output as shown in the following table (from ref. 19):

Performance of Series VIII Prototypes at 2000 K

Diode	I, A	J, A/cm ²	V, volts	Output power, W	T _R , °C	T _C , °C	Input power, W	Effi- ciency, η	Diode weight, g
VIII-P-1 - good quality pyrolytic rhenium emitter	15.4	7.7	1.0	15.4	362	652	---	-----	230
	30.0	15.0	.85	25.5	369	652	---	-----	
	39.0	19.5	.8	31.2	388	652	---	-----	
	60.0	30.0	.688	41.4	384	652	---	-----	
	80.7	40.35	.6	48.4	398	652	---	-----	
VIII-P-2a - pressure- bonded rhenium emitter	24.0	12.0	1.0	24.0	349	529	300	0.08	494
	34.0	17.0	.9	30.6	347	561	325	.0942	
	47.5	23.75	.8	38.0	357	616	358	.106	
	61.0	30.5	.7	42.7	372	666	388	.110	
	78.0	39.0	.6	46.8	382	733	450	.104	
VIII-P-2b - pyrolytic rhenium emitter with impurities	12.6	6.3	1.0	12.6	336	543	263	0.0479	494
	16.0	8.0	.9	14.4	338	554	270	.0534	
	24.0	12.0	.8	19.2	348	584	292	.0658	
	32.0	16.0	.7	22.4	355	623	310	.0724	
	47.0	23.5	.6	28.2	376	702	350	.0806	
VIII-P-3 - pressure- bonded rhenium emitter	29.0	14.5	1.0	29.0	353	661	310	0.0936	255
	39.0	19.5	.9	35.1	360	698	335	.1048	
	49.0	24.5	.8	39.2	366	751	365	.1073	
	58.0	29.0	.7	40.6	380	793	385	.1053	
	65.0	32.5	.6	39.0	387	821	400	.0975	

20. Harbaugh, W. E.; Buzzard, R. J.; and Basiulis, A.: The Design and Evaluation of a 400-Watt Thermionic Converter, pp. 360-368.

Emitter Mo apparently; $T_E = 1450^\circ$ to 1800° C

Collector Ni apparently; $T_C = 610^\circ$ to 740° C

Cesium gap $T_R = 335^\circ$ to 345° C

Geometry cylindric; 40 cm²

Output up to 13.75 W/cm²; efficiencies as high as 19.8 percent; good performance maps

Lifetime 2600 hr average for 12 diodes

Comment according to RCA, A-1272 is a high-performance version of A-1197A (Mo, Ni)

Report on the Thermionic Conversion Specialist Conference. IEEE, 1965.

21. Wilson, V. C.: Rapporteur Paper on "Converter Performance" from The International Conference on Thermionic Electrical Power Generation, London, England, pp. 258-265.

Emitter (1) W, (2) Mo, (3) W, (4) Re, (5) W; $T_E =$ (1) 2263 K, (2) 1973 K, (3) 1900 and 2000 K, (4) 1900 K, (5) 2100 K
Collector (1) Ni, (2) unknown, (3) Nb, (4) Nb, (5) Nb; $T_C =$ 898 to 1053 K for (1)
Cesium gap (1) 0.051, (2) 0.3, (3) 0.16, (4) 0.25, (5) 0.25 mm; $T_R =$ 593 to 693 K for (1)
Geometry (1) plane, the rest cylindric
Output (1) over 75 W/cm², (2) 4.2 W/cm², (3) 5 to 8.4 W/cm², (4) 3.75 W/cm², (5) 10 W/cm²; efficiency of (2) 8 percent, (3) 11 percent; performance map for (1)

22. van Someren, L.; Lieb, D.; and Kitrilakis, S. S.: Evaluation of Thermionic Emitter Surfaces, pp. 266-275.

Emitter Re (four surface preparations), W; $T_E =$ 1605 to 1975 K for Re, 1630 to 1950 for W
Collector Mo; $T_C =$ optimum
Cesium gap optimum; $T_R =$ optimum
Geometry plane; 3-cm² emitter, 2-cm² collector, guard
Output 22 W/cm² for Re and 14 for W at $T_E =$ 1850 K; 40 W/cm² for Re at 1975 K; fully optimized performance plots

23. Levine, J. D.; Harbaugh, W. E.; and Shoemaker, R. E.: Oxygen as a Controllable, Reversible, and Beneficial Additive in the Cesium Converter, pp. 276-280.

Emitter Re; $T_E =$ 1350° C
Collector Ag; $T_C =$ 350° to 550° C
Cesium gap 0.356 mm; $T_R =$ 285° and 290° C
Additive O₂ introduced through Ag membrane on collector
Geometry plane
Output 4.6 W/cm² with 11.6 percent efficiency at 0.2 V, $T_C =$ 400° C, and $T_R =$ 285° C; performance plots

24. Lieb, D.: Performance of Tungsten-Emitter Thermionic Converter in the Presence of Cesium Fluoride Additive, pp. 281-288.

Emitter W; $T_E =$ 1630 to 1950 K

Collector Mo; $T_C = 813$ to 943 K
 Cesium gap 0.025 to 0.762 mm; $T_R = 480$ to 645 K
 Additive CsF; $T_{CsF} = 378$ to 770 K
 Geometry plane, guarded
 Output 40 W/cm² at 0.58 V for Cs + CsF, $T_E = 1870$ K, $T_C = 893$ to 943 K, $T_{CsF} = 623$ K, $T_R = 538$ to 609 K, $d = 0.127$ mm; 9 W/cm² at 0.58 V for Cs alone, $T_E = 1850$ K, $T_C = 862$ K, $T_R = 562$ to 635 K, $d = 0.153$ mm; good performance plots

25. Lawrence, J.; and Perdew, J. P.: Effect on Thermionic Converter Performance of Emitter Material Evaporated on a Low Work Function Collector, pp. 289-296.

Emitter W; $T_E = 1633$ to 2183 K
 Collector Ni or W (from emitter) on Ni; $T_C = 863$ to 973 K
 Cesium gap 0.051 mm; $T_R = 553$ to 663 K
 Geometry plane, guarded
 Output at 100 A/cm², 78 W/cm² (2183 K), 65 W/cm² (2074 K), 47 W/cm² (1963 K), and 35 W/cm² (1855 K) for Ni and 20 W/cm² (1855 K) for W on Ni; subsequent contamination nearly regenerated the initial performance; good I, V curves

26. Blue, E.; and Ingold, J. H.: The Effect of High Collector Temperature on the Power Output and Efficiency of a Thermionic Converter: Experimental, pp. 297-305.

Emitter W; $T_E = 2150$ or 2225 K
 Collector Ta; $T_C = 1355$ to 1675 K
 Cesium gap 0.051 to 0.432 mm; $T_R = 633$ to 693 K and optimum
 Geometry plane, guarded
 Output at $T_E = 2225$ K, $T_C = 1500$ K, $T_{Cs} = 673$ K, $d = 0.135$ mm, 27.5 W/cm² maximum for 0.45 V and 9 percent efficiency and 10.5 percent maximum efficiency; extensive performance plots show effects of high collector temperatures

27. Kitrilakis, S.; and Brosens, P.: Experimental Correlation of Electron Emission Cooling and Optimum Collector Temperature, pp. 316-324.

Emitter Re; $T_E = 1680$ to 2000 K
 Collector Mo; $T_C = 873$ to 1073 K
 Cesium gap 0.013 to 0.508 mm; $T_R = 543$ to 630 K
 Geometry plane, guarded

Output 5.3 W/cm^2 at 0.38 V , $T_E = 1740 \text{ K}$, $T_C = 1053 \text{ K}$, $T_R = 588 \text{ K}$,
 $d = 0.102 \text{ mm}$; I, V plots; an attempt to correlate optimum collector temperatures

Conference Record of the Thermionic Conversion Specialist Conference. IEEE, 1966.

28. Gilliland, D. L.: Performance and Life Test of a Cylindrical Thermionic Converter, pp. 1-5.

Emitter W (UO_2 backed); $T_E = 1500^\circ$ to 1830° C
Collector Ni; $T_C = 700^\circ \text{ C}$
Cesium gap 0.127 mm ; $T_R = 330^\circ$ to 370° C
Additive U and O possible
Geometry cylindric; 1-cm diameter, 8.6 cm^2
Output 18.8 W/cm^2 maximum measured for $T_E = 1830^\circ \text{ C}$; 10.2 W/cm^2 and
15.8 percent efficiency during life test at $T_E = 1730^\circ \text{ C}$,
 $T_C = 700^\circ \text{ C}$, and $T_R = 345^\circ \text{ C}$
Lifetime 9227 hr before shorting out

29. Lawrence, J.; and Wilson, V. C.: A Comparison of Niobium and Nickel as Thermionic Converter Collector Materials, pp. 6-11.

Emitter W; $T_E = 1673$ to 2153 K
Collector Nb or Ni; $T_C = 873$ to 1173 K
Cesium gap 0.025 to 0.508 mm ; $T_R = 583$ to 683 K
Geometry plane
Output voltage is 0.1 to 0.16 V higher with Ni rather than Nb; good performance curves

30. Hobbs, R. L.; and Psarouthakis, J.: A Converter with Vapor Deposited Tungsten Emitter, pp. 12-18.

Emitter Cl⁻CVD (~ 110) W; $T_E = 1900$ to 2000 K
Collector Mo; $T_C = 833$ to 1033 K
Cesium gap 0.203 mm ; $T_R = 563$ to 588 K
Geometry plane
Output 11 W/cm^2 with 0.5 V at $T_E = 2000 \text{ K}$; 9 W/cm^2 with 0.45 V at
 $T_E = 1900 \text{ K}$

31. Kitrilakis, S. S.; and Rufeh, F.: The Output Characteristics of an Electroetched Rhenium Surface, pp. 19-26.

Emitter Electroetched Re; $T_E = 1555$ to 1960 K

Collector Mo; $T_C = 843$ to 943 K and optimum
 Cesium gap 0.013 to 1.016 mm and optimum; $T_R = 514$ and 616 K and optimum
 Geometry plane, guarded
 Output fully optimized, 3 W/cm^2 with 0.2 V at $T_E = 1560 \text{ K}$, 7.5 W/cm^2 with 0.3 V at $T_E = 1650 \text{ K}$, 13 W/cm^2 with 0.5 V at $T_E = 1740 \text{ K}$, 18 W/cm^2 with 0.7 V at $T_E = 1860 \text{ K}$, and 40 W/cm^2 with 0.8 V at $T_E = 1960 \text{ K}$; electroetched Re is considerably more effective than electropolished Re

32. Case, J. M.: An Investigation of Thermionic Converter Dynamic Operation, pp. 47-56.

Emitter W, 20 percent Re; $T_E = 1500^\circ$ to 1800° C
 Geometry cylindric
 Output little information to define performance given in this dynamics study; influences of T_C and T_R considered negligible

33. Sutherland, C. D.; and Ranken, W. A.: Optimization of a Thermionic Diode, pp. 57-65.

Emitter W; $T_E = 2100 \text{ K}$ maximum
 Collector Mo or Ni; $T_C = 1000 \text{ K}$
 Cesium gap 0.127 or 0.178 mm; $T_R = 598$ or 643 K
 Geometry cylindric; 1.2-cm diameter, variable length (for the analysis)
 Output previous data used as bases for numerical optimizations with respect to emitter length and support and output voltage

34. Cahen, O.; and Defranould, P.: Resultats Experimentaux Obtenus Sur des Convertisseurs du Type Nucléaire à Cesium et Fluorure de Césium, pp. 66-69.

Emitter Mo; $T_E = 1450^\circ$ and 1700° C
 Collector Mo; T_C optimum
 Cesium gap 0.25 mm; T_R optimum
 Additive CsF; $T_{CsF} = 325^\circ$ to 550° C
 Output at 2 W/cm^2 6.7 percent efficiency for Cs and 8 percent for Cs + CsF; at 4 W/cm^2 9.7 percent efficiency for Cs and 10 percent for Cs + CsF; at 6 W/cm^2 11.7 percent efficiency for Cs and 10.9 percent for Cs + CsF

35. Rufe, F.; and Kitrilakis, S. S.: Thermionic Converter Performance in Presence of Inert Gases, pp. 91-98.

Emitter $T_E = 1863, 1740, 1645 \text{ K}$

Collector	$T_C = 873 \text{ K}$
Cesium gap	0.051, 0.254, 0.508 mm; $T_R = 558 \text{ to } 638 \text{ K}$
Additive	0 to 100 torr
Geometry	plane, guarded
Output	increasing Ar pressure decreases diode output; 10 torr of Ar attenuates electron current 5 to 15 percent

36. Rufeh, F.: The Volt-Ampere Characteristics of a Grooved-Collector Thermionic Diode, pp. 99-105.

Emitter	$T_E = 1625, 1645 \text{ K}$
Collector	Mo with and without grooves; $T_C = 773, 873 \text{ K}$
Cesium gap	0.025 to 0.635 mm; $T_R = 553 \text{ K}, 593 \text{ K}, \text{ and variable}$
Geometry	plane, guarded
Output	small increase in output for grooved collector over flat one even without optimization

37. Lazaridis, L. J.; and Pantazelos, P. G.: Design of a 5-Kilowatt Flame-Heated Thermionic Power Supply, pp. 126-132.

Emitter	W; $T_E = 1400^\circ \text{ C}$
Collector	Ni
Cesium gap	0.254 mm
Geometry	20 cm^2
Output	5 W/cm^2 at 0.55 V and 10 percent efficiency

38. Harbaugh, W. E.; and Longsderff, R. W.: The Development of an Insulated Thermionic-Converter/Heat-Pipe Assembly, pp. 139-143.

Emitter	Mo; $T_E = 1300^\circ \text{ to } 1500^\circ \text{ C}$
Collector	Mo; $T_C = 625^\circ \text{ to } 675^\circ \text{ C}$
Cesium gap	$T_R = 265^\circ \text{ to } 325^\circ \text{ C}$
Geometry	cylindric, 40 cm^2
Output	2.05 W/cm^2 (0.25 V), 2.8 W/cm^2 (0.28 V), 4.0 W/cm^2 (0.32 V), 5.0 W/cm^2 (0.38 V), 6.9 W/cm^2 (0.45 V)

39. Shefsiek, P. K.: Thermal Measurements of a Thermionic-Converter/Heat-Pipe System, pp. 169-174.

Emitter	Mo; $T_E = 1450^\circ \text{ to } 1530^\circ \text{ C}$
Collector	Mo; $T_C = 475^\circ \text{ to } 710^\circ \text{ C}$
Cesium gap	$T_R = 95^\circ \text{ to } 321^\circ \text{ C}$
Geometry	cylindric; 50 cm^2
Output	3.2 W/cm^2 at 0.6 V, $T_E = 1510^\circ \text{ C}$, $T_C = 710^\circ \text{ C}$, $T_R = 318^\circ \text{ C}$

40. Campbell, A. E.; and Jensen, A. O.: Performance of Prototype Thermionic Converters, pp. 175-184.

Emitter Re; $T_E = 1735^\circ \text{C}$
Collector Re or Mo; $T_C = 507^\circ$ to 790°C
Cesium gap 0.089 mm (Re, Re), 0.0051 mm (Re, Re), 0.089 mm (Re, Mo)
Geometry plane; 2.0 cm^2 faces, 0.4 cm^2 sidewalls
Output 20 W/cm^2 at 0.8 V for Re, Re diode with 0.051-mm gap; 15.2 W/cm^2 at 0.8 V, 21.0 W/cm^2 at 0.7 V, 26.4 W/cm^2 at 0.6 V for Re, Re diode with 0.089-mm gap; Re collector gave average of 0.08 V more than its Mo counterpart

41. Rouklove, P.: Thermionic Converter and Generator Tests, pp. 185-191.

Emitter Re; $T_E = 1600^\circ$, 1700° , 1800°C
Collector Mo; radiation cooled (T_C near optimum)
Cesium gap 0.038 mm; T_R optimum
Geometry plane SET diodes; 2.5 cm^2
Output 25 W/cm^2 (0.6 V), 21 W/cm^2 (0.7 V), 15.7 W/cm^2 (0.8 V) with efficiencies near 12.5 percent

42. Brosens, P. J.: The Influence of Design and Materials on the Performance of an Advanced Solar Converter, pp. 192-196.

Emitter Re or Ta; $T_E = 2000 \text{ K}$
Collector Mo; radiation cooled (T_C near optimum)
Cesium gap T_R optimum
Geometry solar energy thermionics (SET) (plane); as described in the following table (from ref. 42):

DESCRIPTION OF PROTOTYPE DIFFERENCE

Prototype	100	101	102	103	104	201	202	203	204	205
Emitter material	Ta	Ta	Re	Re	Re	Re	Re	Re	Re	Re
Emitter fabrication	M	M	B	B	B	B	B	B	M	M
Emitter preparation	G	G	G	G	G	PE	PE	PE	E	E
Emitter support material	Ta	Ta	Ta	Ta	Ta	Ta	Ta	Ta	Re	Re
Collector material	Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo
Collector preparation	G	L	L	L	L	L	C	C	C	M
Collector lateral area ^a , cm ²	0.5	0.5	0.5	1.3	0.5	2.0	2.0	1.0	1.0	1.0
Nominal spacing, mm	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.045	0.107
Measured spacing, mm	0.035	-----	0.025	-----	0.025	0.035	0.041	0.033	0.045	0.107
Lateral spacing, mm	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.152	0.102
Internal radiation shield	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Compression jig	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Amperes at 0.8 V, 2000 K	26.5	24	42	42.5	34	27.8	44.5	40	46.5	41.5
Amperes at 1.0 V, 2000 K	18.5	16.8	32	31	27	20.5	14	23	26	22

^aCollector plane area, 2.5 cm².

43. Bohdansky, J.; and van Andel, E.: Heat-Pipe Thermionic Converter with a Graphite Absorption Cesium Reservoir Working at Collector Temperature, pp. 239-242.

Emitter Cl⁻CVD W (110); T_E = 1755, 1825, 2000 K
Collector Ni; T_C = 843 to 1183 K
Cesium gap 0.10 mm; Cs, graphite reservoir at collector temperatures
Geometry plane, ceramic guarded
Output 4.2 W/cm² at 0.5 V, T_E = 2000 K, T_C = 1183 K

44. Lieb, D.; and Kitrilakis, S. S.: Oxygen as a Steady-State Electronegative Additive in a Cesium Thermionic Converter, pp. 348-354.

Emitter Re; T_E = 1650 to 1850 K
Collector Mo; T_C = 573 to 773 K
Cesium gap 0.127, 0.254, 0.508 mm; T_R = 481 to 538 K
Additive Cs₂O, O₂; collector acted as Cs₂O reservoir
Geometry plane, guarded
Output 6.8 W/cm² for Cs + Cs₂O, 4.4 W/cm² for Cs only at 0.4 V,
 T_E = 1750 K with 0.254-mm gap; for Cs + Cs₂O I, V curves for
 0.127 and 0.508 mm are nearly identical at T_E = 1750 K

45. Long, J. D.; and Psarouthakis, J.: Collector Work Function Investigations in Cesium and Barium-Cesium Vapors, pp. 355-364.

Emitter Ru; T_E = 1425^o to 1627^o C
Collector Mo; Nb; Nb (O) (oxygenated Nb); Re; Ru; T_C = 390^o to 570^o C

Cesium gap 0.127, 0.152 mm; $T_R = 175^\circ$ to 345° C
 Additive Ba (Cs diode containing Ba shorted internally without yielding data)
 Geometry plane, unguarded; 1.18 cm^2
 Output as shown in the following table for $T_E = 1627^\circ$ C, T_R optimum,
 $d = 0.152$ mm:

Collector	Nb	Ru	Nb(O)	Re	Mo	Ru
$T_C, ^\circ\text{C}$	570	570	570	517	517	517
W/cm^2	11	10	10	10	8.5	6.5

46. Backus, C. E.; and Davis, M. V.: The Effect of Iodine and the Inert Gases as Additives in a Cesium Arc Diode, pp. 376-381.

Emitter Ta; $T_E = 1850$ K
 Collector Ni; $T_C = 725$ K
 Cesium gap 0.762 mm; T_R optimum
 Additive Ar, Kr, Xe, I
 Geometry plane; 2.38-cm diameter
 Output for Cs alone, 1.4 W/cm^2 maximum; output dropped steadily with increasing inert-gas pressure and produced at 30 torr and 0.6 V decreases of 46 percent for Ar, 76 percent for Kr, 83 percent for Xe; with I output at 0.6 V increased by 110 percent at 36 torr, then diminished to the initial (Cs only) value at 120 torr

47. Jester, A.; Gross, F.; Holick, H.; and Busse, C. A.: A Nuclear Heated Thermionic Converter, pp. 419-425.

Emitter Mo; $T_E = 1460$ to 2010 K
 Collector Nb; $T_C = 923$ to 953 K
 Cesium gap 0.204 mm; T_R optimum
 Geometry cylindric; 1.6-cm diameter, 20 cm^2
 Output 9 W/cm^2 with 11 percent efficiency at $T_E = 2000$ K, $T_R = 360^\circ$ C (optimum); in-core performance plots

Conference Record of the Thermionic Conversion Specialist Conference. IEEE, 1967.

48. Wilson, V. C.; and Lawrence, Jackson: Characteristics of a Thermionic Converter with a Fluoride Vapor Deposited Tungsten Emitter Etched to Preferentially Expose the 110 Crystal Planes, pp. 1-9.

Emitter F⁻CVD W (100) etched to expose 110 W faces and 40 percent more area; T_E = 1650 to 2150 K
Collector Nb; T_C optimum
Cesium gap 0.025 to 0.508 mm; T_R optimum
Geometry plane, guarded
Output 42 W/cm² with 50 A/cm², 20 percent efficiency and 30 W/cm² with 30 A/cm², 23 percent efficiency for d = 0.051 mm, T_E = 2155 K, T_C = 973 K; unusually high outputs at low Cs pressures and large spacings; greatest outputs came with gaps of 0.254 mm or more; good performance maps
Lifetime performance decayed because of thermal reforming at 2155 K

49. Howard, R. C.; von Someren, L.; and Yang, L.: Preliminary Results on the Thermionic Performance of a Vapor-Deposited Tungsten Emitter Having (110) Preferred Orientation, pp. 10-12.

Emitter Cl⁻CVD W (110); T_E = 1700, 1735, 1850 K
Collector Mo; T_C = 470° to 660° C
Cesium gap 0.127 mm
Geometry plane, unguarded
Output 16 W/cm² at 0.5 V, T_E = 1850 K; 9.8 W/cm² at 0.39 V, T_E = 1700 K

50. Holland, J. W.; and Kay, J.: Performance of a Cylindrical Geometry Thermionic Converter with an Improved Work Function Tungsten Emitter, pp. 13-17.

Emitter F⁻CVD W (100); Cl⁻CVD W (110); T_E = 1600° to 1800° C
Collector Mo; Nb; T_C optimum
Cesium gap 0.229 mm; T_R optimum
Geometry cylindric thermionic fuel (nuclear) elements (TFE's)
Output Cl⁻CVD W emitter gave 25 percent more power than F⁻CVD W; Mo collector, 40 percent more than Nb at optimum current densities
Lifetime over 3600 hr for F⁻CVD-W, Nb diode; over 6000 hr for Cl⁻CVD-W, Nb diode

51. Koskinen, M. F.; and Gammel, G.: A Direct Comparison of Molybdenum and Nickel as Collector Materials, pp. 18-24.

Emitter None
Collector Comparison of Ni and Mo; T_C = 400° to 730° C
Cesium gap 0.210 mm cold, 0.15 mm at 700° C; T_R < 485 K
Geometry plane double-collector isothermal diode; 4 cm²
Output Mo collector was superior to Ni, giving 0.05 to 0.14 V lower cesiated surface potentials

52. Rufeh, F.; Lieb, D.; and Fraim, F.: Recent Experimental Results on Electro-negative Additives, pp. 25-28.

Emitter $T_E = 1500$ to 1900 K
Cesium gap $T_R = 433$ to 638 K
Additive CsO_2 , O
Geometry plane, fixed-gap
Output CsO_2 increased Cs diode performance considerably; diode was run with Cs only, then with Cs + Cs_2O , and finally with Cs alone; Cs_2O improved performance, reduced Cs pressure, decreased electron scattering in gap, and allowed operation with higher diode-component temperatures; performance curves

53. Shimada, Katsunori: Apparent Work Function of Cavity Emitters, pp. 29-32.

Emitter Ta with cavities; $T_E = 1200$ to 2100 K
Collector Mo; $T_C = 400^\circ$ C
Cesium gap 0.051 mm; 0.324 to cavity bottoms
Geometry plane, unguarded; 2 cm^2
Output work functions from saturation currents and J, V curve knees were 0.4 eV lower than predicted by Rasor, Warner theory

54. Rufeh, F.; and Lieb, D.: Volt-Ampere Characteristics in the Presence of Inert Gases, pp. 33-37.

Emitter $T_E = 1800$ K
Collector T_C optimum
Cesium gap 0.254 , 1.016 mm; T_R optimum
Additive Xe, Kr, 0 to 213 torr
Output both Kr and Xe decreased diode performance with increasing pressure; at $T_E = 1800$ K, $d = 0.254$ mm a 20 percent current drop resulted for 60 torr Xe or for 100 torr Kr; previous reports of output gains with inert gas additions probably resulted from oxygen contamination

55. Bliaux, J.; and Clémot, M.: In Pile Thermionic Life Test Sirene 302, pp. 38-46.

Emitter CVD W; $T_E = 1350^\circ$ to 1700° C
Collector Nb, 1 percent Zr; $T_C = 741^\circ$ to 814° C
Cesium gap 0.16 mm; $T_R = 693^\circ$ to over 860° C
Additive emitter backed by 20 percent enriched UO_2
Geometry cylindric; 4 cm long, 20 cm^2

Output 4.25 W/cm² with 10.6 percent efficiency at 0.78 V, T_E = 1695° C,
T_C = 763° C, T_R = 810° C
Lifetime 1650 hr without degradation

56. Speidel, T.: Performance Comparison of Nine RD-502 Cylindrical Diodes with Etched Rhenium Emitters, pp. 47-50.

Emitter etched Re
Collector Nb; PVD Mo
Geometry cylindric; 3.81 cm long, 15 cm²
Output as shown in the following table (from ref. 56):

RD-502 DIODES WITH ETCHED RHENIUM EMITTERS

Diode data	2	4	12	6	7	8	9	10	11
Serial number	2	4	12	6	7	8	9	10	11
Customer	AEC	AEC	JPL	MEL	MEL	MEL	MEL	MEL	MEL
Emitter	Re	Re	Re	Re	Re	Re	Re	Re	Re
Collector	Mo	Mo	Mo	Nb	Nb	Nb	Mo	Mo	Mo
Spacing, mm	0.254	0.254	0.203	0.127	0.127	0.127	0.127	0.127	0.127
600-Watt input									
Maximum device efficiency, percent	10.1	9.8	9.2	9.4	9.0	9.2	9.0	9.4	9.2
Maximum output, W/cm ²	4.0	3.9	3.7	3.8	3.6	3.7	3.6	3.8	3.7
750-Watt input									
Maximum device efficiency, percent	12.7	11.3	12.4	12.6	---	10.8	11.2	13.2	11.7
Maximum output, W/cm ²	6.4	5.7	6.2	6.3	---	5.4	5.6	6.6	5.9
900-Watt input									
Maximum device efficiency, percent	13.8	13.5	13.8	13.3	13.2	12.5	13.3	14.5	11.5
Maximum output, W/cm ²	8.3	8.1	8.3	8.0	7.9	7.5	8.0	8.7	6.9
Life test									
Hours attained	1221	100	0	146	211	148	650	1272	1001
Stopped by	Open circuit	Program	----	Program	Water failure	Program	Program	Program	Program

57. Paquin, M. L.: Testing of a Calorimeter-Equipped Planar Thermionic Converter, pp. 51-55.

Emitter etched Re; T_E = 1860 K
Collector VD Mo; T_C = 973 K
Cesium gap 0.114 mm; T_R = 289° to 373° C
Geometry plane; 1.77 cm²
Output as shown in the following table (from ref. 57):

DATA SUMMARY

Output voltage, volts	Input power density, W/cm ²		Output power density, W/cm ²		Device efficiency, percent	
	Measured	Calculated	Measured	Calculated	Measured	Calculated
0.40	104	112	12.8	12.4	10.1	11.1
.40	101	101	13.7	13.3	11.1	13.2
.60	94	86	12.9	12.5	13.3	14.5
.65	58	66	9.0	8.7	12.7	13.4
.70	48	55	6.8	6.6	11.6	12.0
.75	42	49	5.5	5.3	10.5	10.5
.80	35	43	4.0	3.9	9.8	9.2

58. Brosens, Pierre J.: Advanced Converter Development, pp. 68-73.

Emitter etched Re; $T_E = 1800, 1900, 2000$ K

Collector Nb; Pd; Re

Cesium gap 0.051 mm; T_R optimum

Geometry plane; 2.5 cm²

Output diode voltages decreased by averages of 0.037 V for Pd and 0.074 V for Nb relative to those for Re collector

59. Rouklove, Peter: Thermionic Converter and Generator Tests, pp. 75-85.

Emitter Re; $T_E = 1600^\circ$ to 1800° C

Collector Mo; T_C optimum

Cesium gap T_R optimum

Geometry plane SET diodes

Output as shown in the following tables (from ref. 59):

Table 1. - Performance of SET-type converters

Parameters	1962	1963	1964	1965	1966	1967	Improvement factor
Power output, W	12	25	36	44	50	45	3.75
Power density, W/cm ²	6	12	18	22	20	18	3
Efficiency, percent	3	5	8	12.5	10	11	3
Maximum life, hr	119	1500	3200+	13 150+	15 210	N. A.	128
Vibration, 20 g at 0 to 2000 cps	-----	-----	-----	Passed	Passed	N. A.	-----
Shock, 100 g, 0.5 msec	-----	-----	-----	Passed	Passed	N. A.	-----
Power to weight ratio, W/kg	4.30	9.04	14.8	15.9	18.5	574	133
Weight/kW, kg/kW	23.2	11.1	8.66	7.08	7.68	1.74	15.1

Table 2. - Converter characteristics

Parameter	VIII-15				VIII-17				VIII-25				VIII-26			
	$T_e = 1700^\circ \text{C}$		$T_e = 1800^\circ \text{C}$		$T_e = 1700^\circ \text{C}$		$T_e = 1800^\circ \text{C}$		$T_e = 1700^\circ \text{C}$		$T_e = 1800^\circ \text{C}$		$T_e = 1700^\circ \text{C}$		$T_e = 1800^\circ \text{C}$	
$E_b, \text{ v}$	0.8	0.6	0.8	0.6	0.8	0.6	0.8	0.6	0.8	0.6	0.8	0.6	0.8	0.6	0.8	0.6
$T_b, \text{ A}$	42.5	75.3	63.5	85.5	70.0	84.0	54.5	84.0	35.1	66.3	59.0	81.5	33.3	64.5	60.0	82.5
$w, \text{ w}$	34	45	51	51	42	50	48	50	28	40	47	49	27	39	48	50
$E_{oc}, \text{ v}$	2.1	1.7	1.8	1.6	1.9	1.7	1.9	1.7	2.1	1.8	1.8	1.7	2.0	1.7	1.2	1.6
$w_{in}, \text{ w}$	344	445	469	532	330	409	434	518	311	399	447	518	302	396	462	526
Efficiency, percent	9.9	10.2	10.8	9.7	10.3	10.3	11.0	9.7	9.0	10.0	10.6	9.4	8.8	9.8	10.4	9.4
$T_{cs}, ^\circ \text{C}$	321	353	344	352	330	346	348	353	316	344	345	354	311	332	341	360
$T_{seal}, ^\circ \text{C}$	586	657	658	705	602	667	672	730	597	674	678	719	593	669	679	728
$T_{col}, ^\circ \text{C}$	624	764	724	850	577	683	668	720	610	737	745	819	617	762	765	873
$T_{rad}, ^\circ \text{C}$	540	625	622	680	533	605	612	657	530	615	617	666	524	615	617	675

60. Lazaridis, L.; Shai, I.; and Shefsiek, P.: Development of a 300-Watt Flame-Heated Thermionic Power Supply, pp. 86-92.

Emitter W; $T_E = 1380^\circ, 1425^\circ, 1450^\circ \text{ C}$
 Collector Ni; $T_C = 580^\circ \text{ C}$
 Cesium gap 0.254 mm
 Geometry 29 cm^2
 Output 2.9 W/cm^2 at 8.6 percent efficiency, $T_E = 1380^\circ \text{ C}$

61. Bohdanský, J.; Salamon, K.; and van Andel, E.: Integrate Cs-Graphite Reservoir System in a Heat Pipe Thermionic Converter, pp. 93-96.

Emitter W; $T_E = 1640 \text{ to } 1930 \text{ K}$
 Collector W; T_C optimum
 Cesium gap 0.5 mm; $T_R \approx T_C$ for Cs, C compound reservoir
 Geometry plane
 Output 1.8 W/cm^2 ($T_E = 1640 \text{ K}$) to 4.1 W/cm^2 (1930 K)

62. Koskinen, M. F.; Gammel, G.; Gross, F.; DeTroyer, A.; Ne've de Mévergnies, E.; and Dejonghe, P. A. J.: An Actinium-227 Fueled Thermionic Generator, pp. 102-109.

Emitter single crystal 110 W; $T_E = 1800 \text{ K}$
 Collector Mo; $T_C = 981 \text{ K}$
 Cesium gap 0.2 mm; $T_R = 603 \text{ K}$
 Geometry plane; 4 cm^2
 Output 5.3 W/cm^2 at 0.53 V

63. Gronroos, Henrik G.; Davis, Jerry P.; Weaver, Lynn E.; and Guppy, James G.: A Control System Study for an In-Core Thermionic Reactor, pp. 130-137.

Emitter W; $T_E = 1500 \text{ to } 2000 \text{ K}$
 Collector Mo; T_C optimum
 Cesium gap 0.254 mm; T_R optimum
 Output SIMCON performance plots; as shown in the following table:

Emitter temperature, K	1500	1600	1700	1800	1900	2000
Power maximum, W/cm^2	1.5	2.3	3.5	5.2	7.3	9.7
Efficiency maximums, percent	7.3	9.3	10.2	12.3	13.8	15.2

Conference Record of the Thermionic Conversion Specialist Conference. IEEE, 1968.

64. Shefsiek, P. K.: Reproducibility of Thermionic Performance, pp. 99-102.

Emitter Re; $T_E = 1975, 2000$ K
 Collector Mo; $T_C = 773$ to 1093 K
 Cesium gap 0.051 mm; $T_R = 583$ to 633 K
 Geometry plane; 2 cm^2
 Output average of 12 diodes 18.8 W/cm^2 (17.5 to 20.3) at 0.7 V,
 $T_E = 2000$ K, $T_{C, \text{ave}} = 1045$ K, $T_{R, \text{ave}} = 630$ K

65. Merrill, O. S.: Correlation of Fixed-Spacing Thermionic Converter Performance with Variable-Spacing Test Vehicle Data, pp. 103-112.

Emitter Re (polycrystal or vapor-deposited); $T_E = 1600$ to 2100 K
 Collector Re (polycrystal or vapor-deposited); $T_C = 983$ to 993 K and optimum
 Cesium gap 0.080 to 0.305 mm; $T_R = 562$ to 604 and optimum
 Geometry seven plane diodes, 2 cm^2 ; one cylindric, 2 cm^2
 Output for 0.127 mm, maximums are 24 W/cm^2 (0.69 V, $T_E = 2100$ K),
 20 W/cm^2 (0.60 V, $T_E = 2000$ K), 17 W/cm^2 (0.52 V, $T_E = 1900$ K),
 11.4 W/cm^2 with 8.9 percent efficiency (0.41 V, $T_E = 1800$ K),
 7 W/cm^2 (0.28 V, $T_E = 1700$ K); good performance curves
 Lifetime $11\ 600$ hr for one diode at 27 W/cm^2 , 0.77 V, 2000 K

66. Speidel, T. O.; and Williams, R. M.: Fixed-Space Planar Thermionic Diode with Collector Guard Ring, pp. 113-117.

Emitter Re; Ta; $T_E = 1505^\circ$ to 1680° C
 Collector Nb
 Cesium gap 0.254 mm; T_R optimum
 Geometry plane, guarded; 1.82 cm^2
 Output not maximums but highest tested for each: 14.4 W/cm^2 (Re, 1660° C, 0.4 V), 4.2 W/cm^2 (Ta, 1680° C, 0.3 V)

67. Williams, R. M.; and Kascak, T. J.: A Comparison of the Performance of Two Rhenium, Niobium Cylindrical Thermionic Converters, pp. 118-122.

Emitter F⁻CVD Re mechanically polished or etched; $T_E = 1875$ to 2075 K
 Collector Nb; $T_C = 973$ K for $T_E = 1900$ K and optimum
 Cesium gap 0.254 mm; T_R optimum
 Geometry cylindric; 1.28 -cm diameter, 15.2 cm^2

Output for maximum electrode efficiencies from 1875 to 2075 K, 6.8 to 9.2 W/cm² with 12.6 to 14.6 percent efficiency for mechanically polished Re, 5.5 to 8.3 W/cm² with 11.4 to 13.6 percent efficiency for electroetched Re

68. Kascak, T. J.; and Williams, R. M.: The Performance of a Rhenium, Niobium Cylindrical Thermionic Converter, pp. 123-127.

Emitter vapor-deposited, electroetched Re; $T_E = 1600$ to 2050 K
 Collector Nb; $T_C = 873$ to 1173 K
 Cesium gap 0.254 mm; T_R optimum
 Geometry cylindric; 1.27-cm diameter, 15.2 cm²
 Output for maximum efficiency, 1.2 to 8.1 W/cm² with 5.2 to 13.4 percent efficiency; for maximum power, 1.4 to 8.8 W/cm² with 4.9 to 12.8 percent efficiency

69. Peelgren, M.; and Speidel, T.: Large Cylindrical Thermionic Diode with Rhenium Emitter for Diode Kinetic Experiments, pp. 128-133.

Emitter etched Re; $T_E = 1600^\circ$ and 1770° C
 Collector Mo (Mo, Nb data in comparison); T_C optimum
 Cesium gap 0.254 mm; T_R optimum
 Geometry cylindric; 1.905-cm diameter, 30 cm²
 Output maximum power 3.8 to 9.8 W/cm², maximum efficiency 9.4 to 13.2 percent; results comparable with averages for six Re, Mo and three Re, Nb diodes having 0.178-mm gaps and 15-cm² emitters

70. Wang, C. -C.; and Ward, J. J.: Performance of Chloride and Fluoride Vapor-Deposited Tungsten Emitters in Thermionic Converters, pp. 134-140.

Emitter Cl⁻CVD W (110); F⁻CVD W (100); etched F⁻CVD W (110);
 $T_E = 1600$ to 2000 K
 Collector Nb; T_C optimum
 Cesium gap 0.203 mm; T_R optimum
 Geometry six plane diodes
 Output as shown in the following table for polycrystalline 110 types at 10 A/cm²:

T_E , K	1600	1700	1800	1900	2000
W/cm ²	1.8 to 2.7	3.0 to 4.4	4.8 to 5.5	5.8 to 7.0	7.4 to 8.6

above 1800 K Cl⁻CVD W gave 50 percent higher power densities than F⁻CVD W; below 1700 K Cl⁻CVD W performed better only at low output voltages; etching raised F⁻CVD W outputs to those of Cl⁻CVD W; good performance maps

71. Ruffe, F.; and Lieb, D.: Emission Characteristics of a Duplex Vapor-Deposited Tungsten Emitter, pp. 141 to 150.

Emitter Duplex W (Cl⁻CVD on F⁻CVD); $T_E = 1600$ to 1915 K
 Collector Mo; $T_C = 900$ and 950 K
 Cesium gap 0.013 to 1.016 mm; T_R 's giving 0.5 to 11 torr
 Geometry plane, guarded
 Output excellent performance maps; for optimum spacings and cesium pressures at 10 A/cm² output was as follows:

T_E , K	1600	1700	1800	1900
T_C , K	900	900	950	950
W/cm ²	2.8	3.8	5.6	7.2

72. Ernst, D. M.: Performance Comparison of Four Cylindrical Diodes with Various Types of Tungsten Emitters, pp. 151-154.

Emitter F⁻CVD W (100): (1) as-deposited, (2) etched as-deposited, (3) as-ground, (4) etched as-ground; $T_E = 1800^{\circ}$ C or less
 Collector Nb; T_C optimum
 Cesium gap 0.254 mm; T_R optimum
 Geometry 1.27 -cm diameter, 15 cm²
 Output as shown in the following table:

Diode, φ , eV	1	2	3	4
	4.88	4.55	4.58	4.75
600 W input				
Maximum efficiency, percent	7.7	9.3	7.8	9.0
Maximum power, W/cm^2	3.1	3.8	3.1	3.6
750 W input				
Maximum efficiency, percent	8.9	10.2	9.3	9.7
Maximum power, W/cm^2	4.5	5.1	4.6	4.9
900 W input				
Maximum efficiency, percent	9.8	11.0	10.1	10.2
Maximum power, W/cm^2	5.8	6.6	6.1	6.2

73. Shimada, K.: Side-Wall Currents in Unignited Hardware-Type Thermionic Energy Converters, pp. 155-158.

Emitter Re; $T_E = 1700$ to 2016 K
 Geometry SET plane diode
 Output side-wall-current theory agrees with test results

74. Stapfer, G.; and Shimada, K.: Electrical Testing of a Six-Converter Generator, pp. 159-163.

Emitter Re; $T_E = 1600^\circ$ and 1700° C
 Collector Mo; T_C near optimum (radiation cooling)
 Cesium gap T_R optimum
 Geometry six SET plane diodes in a generator, 2 cm^2 each
 Output for the generator, 140 W at 3.0 V (4.0 V without lead losses),
 4.5 percent efficiency, $T_E = 1700^\circ \text{ C}$; 96 W at 3.0 V (3.75 V without lead losses), 4.5 percent efficiency (at 3.5 V), $T_E = 1600^\circ \text{ C}$;
 averages for the diodes, 11.7 W/cm^2 at 0.67 V , $T_E = 1700^\circ \text{ C}$;
 8 W/cm^2 at 0.62 V , $T_E = 1600^\circ \text{ C}$

75. Hansen, L. K.: Thermionic Research at Stresa (A Review), pp. 178-187.

Emitter $T_E = 1800 \text{ K}$
 Collector T_C optimum

Cesium gap 0.254 mm; T_R optimum
 Additive Ar, Xe
 Output additions of inert gases only degrade diode performance; at 10 A/cm²
 40 torr of Ar caused a drop from 3.4 W/cm² to 2.4 W/cm²

76. Dagbjartsson, S.; Groll, M.; Schlörb, O.; and Pruschek, R.: An Improved Out-of-Core Thermionic Reactor for Low Power, pp. 299-304.

Emitter Re; $T_E = 1850$ K
 Collector Mo probably
 Output 18 W/cm²

77. Lieb, D.; and Rufeh, F.: Thermal Stability as a Function of Converter Performance, pp. 318-322.

Emitter $T_E = 1600$ to 2000 K
 Cesium gap 0.127 to 0.305 mm; $T_R = 548$ to 635 K
 Output I, V curves for high- and low-performance diodes used to show that above-optimum T_R 's insure against in-core thermal runaway

Conference Record of the Thermionic Conversion Specialist Conference. IEEE, 1969.

78. Jacobson, Dean L.; and Campbell, A. E.: The Characterization of Bare and Cesium CVD 75 Percent Tungsten/25 Percent Rhenium Electrodes, pp. 26-33.

Emitter 75 percent W, 25 percent Re; $T_E = 1800, 2000$ K
 Collector 75 percent W, 25 percent Re; $T_C = 927$ to 1000 K
 Cesium gap 0.003 to 0.762 mm; 0.254-mm fixed gap; $T_R = 588$ to 650 K
 Geometry variable-parameter, plane, guarded diode; fixed-gap plane diode; cylindric diode; each 2 cm²
 Output 16 W/cm² at 0.5 to 0.6 V, $T_E = 2000$ K for fixed-gap plane diode; 18 W/cm² at 0.4 to 0.5 V, $T_E = 2000$ K for cylindric diode

79. Pigford, Thomas H.; and Thinger, Byron E.: Performance Characteristics of a 0001 Rhenium Thermionic Converter, pp. 34-38.

Emitter 1-xtal 0001 Re; $T_E = 1600$ to 2000 K
 Collector Nb; $T_C = 933$ K
 Cesium gap 0.254 mm; $T_R = 507$ to 611 K
 Geometry plane, guarded; 0.621 cm²

Output maximum electrode power densities, 5.1 W/cm^2 at $T_E = 1600 \text{ K}$ to 15.4 W/cm^2 at $T_E = 2000 \text{ K}$; at 10 A/cm , $T_C = 933 \text{ K}$, $T_R = \text{optimum}$, power density was as follows:

$T_E, \text{ K}$	1600	1700	1800	1900	2000
W/cm^2	3.6	5.2	6.7	7.8	9.3

80. Wilson, V. C.; and Danko, J. C.: Development of a Stable Faceted Tungsten Emitter Surface, pp. 46-52.

Emitter $\text{F}^- \text{CVD W (100)}$ etched to 110 faces (compared with polycrystalline W, 100 W, and 112 to 114 W); $T_E = 1650$ to 2150 K
Collector Nb; T_C optimum
Cesium gap spacing optimum; T_R optimum
Geometry plane, guarded
Output 4.2 W/cm^2 at 10 A/cm^2 and $T_E = 1650 \text{ K}$ to 13.9 W/cm^2 at 10 A/cm^2 and $T_E = 2150 \text{ K}$
Lifetime 150 hr with no effect at 1980 K ; surface changed after 22 hr at 2130 K

81. Lieb, D.; Donaker, A.; and Ruffe, F.: Performance of a Thermionic Converter with a Nominal Single-Crystal $\langle 110 \rangle$ Tungsten Emitter and a Niobium Collector, pp. 66-75.

Emitter 110 W (several crystals with 110 faces within 4° of emitter surface); $T_E = 1600$ to 2000 K
Collector Nb; $T_C = 700$ to 1025 K
Cesium gap 0.013 to 1.016 mm ; $T_R = 528$ to 653 K
Geometry plane, guarded
Output performance is better than that for a high-output $\text{Cl}^- \text{CVD W}$ diode below 0.47 V at $T_E = 1700 \text{ K}$ and below 0.8 V at $T_E = 1900 \text{ K}$; excellent performance maps; fully optimized at 10 A/cm^2 ; power as shown in the following table:

$T_E, \text{ K}$	1600	1700	1800	1900	2000
W/cm^2	3.1	4.7	6.2	7.8	10.0

82. Wilson, V. C.: A Review of Thermionic Converter Tests, pp. 82-89.

Emitter	several orientations and surface preparations for W and for Re; W, 25 percent Re; Mo; Ta; $T_E = 1650$ to 2150 K
Collector	W + WO_2 on Nb; Mo; Nb; Ni; Re; T_C optimum
Cesium gap	0.051 to 0.508 mm and optimum; $T_R = 513$ to 633 K and optimum
Geometry	plane
Output	excellent condensation and comparison of output results mostly for high-performance diodes

83. Breitwieser, Roland; Manista, Eugene J.; and Smith, Arthur L.: Computerized Performance Mapping of a Thermionic Converter with Oriented Tungsten Electrodes, pp. 90-99.

Emitter	single-crystal 110 W; $T_E = 1550$ to 1950 K
Collector	single-crystal 110 W; $T_R =$ four temperatures around peak-power point
Cesium gap	0.025 to 0.305 mm; $T_R = 520$ to 600 K
Geometry	plane, guarded; 1.02-cm diameter
Output	for 0.203 mm and $T_R = 600$ K maximums were 3 W/cm^2 at 0.4 V, $T_E = 1750$ K; 3.8 W/cm^2 at 0.4 V, $T_E = 1850$ K

84. Clemot, M.; Gayte, B.; Lebourg, R.; and Tripet, J.: Life Testing and Performance Stability of Cylindrical Thermionic Converters, pp. 100-108.

Emitter	F ⁻ CVD W (100); $T_E = 1300^\circ$ to 1650° C
Collector	Mo or Nb, 1 percent Zr; T_C optimum
Cesium gap	0.20 to 0.25 mm; T_R optimum
Geometry	cylindric, 20 cm^2
Output	as shown in the following table (from ref. 84):

Serial number	COL 130	COL 135	COL 134	COP 140	312	314	308	310
Emitter Collector Cold spacing, μ	Mo/W, 60 μ Mo 230	Mo Mo 250	Mo/W, 85 μ Mo 200	Mo/W, 150 μ Mo 200	Mo/W, >200 μ Nb, 1 $\frac{1}{2}$ Zr 200	W, 2 mm Nb, 1 $\frac{1}{2}$ Zr 200	Mo/W, >200 μ Nb, 1 $\frac{1}{2}$ Zr 200	Mo/W, >200 μ Nb, 1 $\frac{1}{2}$ Zr 200
$p_E = 40 \text{ W/cm}^2$, $T_E \approx 1470^\circ \text{C}$ Maximum total efficiency, percent Maximum out- put, W/cm^2	11.3 4.5	8.7, 15 3.45, 6	10 4	11.8 4.7	9.3 3.7	9.5 3.84	8.5 3.4	8.2 3.3
$p_E = 50 \text{ W/cm}^2$, $T_E \approx 1600^\circ \text{C}$ Maximum total efficiency, percent Maximum out- put, W/cm^2	11.8 5.9	9.4, 16 4.7, 8	11 5.5	14 7	10 5	9.6 4.8	9.9 4.9	10.3 5.15
Life tests, hr	4600	1125	5256	1860	2400	1100	8500	5000
Cause of failure	S. C., W emitter peeling off and blistering	S. C., Mo emitter transport	S. C., W emitter had localized blisters	S. C., W emitter had localized blisters	S. C.	Cs leak at the E, C insulator	Still running	Voluntarily stopped
Remarks	Bad CVD con- dition (WC_{16}), first S. C. at 3300 hr	High perform- ance followed by rapid deg- radation	W transport ma- terial (emitter to collector)	W transport ma- terial (emitter to collector)	Under post- test examin- ation	Under post- test examin- ation		Water leak in environment

85. Gunther, B.: Converter Performance Comparison, pp. 109-114.

Emitter F^-CVD W (100); $T_E = 1600$ to 2000 K
 Collector Nb; T_C optimum
 Cesium gap 0.254 mm; $T_R = 330^\circ$ to 400° C
 Geometry 12 cylindric diodes, each 20 cm^2
 Output as shown in the following table (with a 3.7 percent standard deviation):

T_E , K	1760	1860	1960
P_{\max} , W/cm ²	3.0	4.6	5.9
η_{\max} , percent	7.5	9.2	9.9

86. Samstad, G. I.; Case, J. M.; and Danko, J. C.: Design, Operation and Post-Test Analysis of a High Performance Cylindrical Converter, pp. 115-121.

Emitter Cl^-CVD W (110); $T_E \approx 1700^\circ$ C
 Collector Nb; $T_C \approx 700^\circ$ C
 Cesium gap 0.254 mm; $T_R = 340^\circ$ to 372° C
 Geometry cylindric; 1.42-cm diameter, 11.0 cm^2
 Output 7.4 W/cm^2 maximum at $T_E = 1700^\circ$ C, $T_C = 700^\circ$ C, $T_R = 360^\circ$ C;
 9.5 W/cm^2 maximum at $T_E = 1710^\circ$ C, $T_C = 710^\circ$ C, $T_R = 354^\circ$ C
 after 5000 hr
 Lifetime removed after 5000 hr for examination

87. Hamerdinger, Randolph W.; and Jacobson, Dean L.: Design and Performance of Low Temperature Cylindrical Thermionic Converters, pp. 122-129.

Emitter Cl^-CVD Re; $T_E = 1573, 1673, 1800$ K
 Collector Cl^-CVD Re; $T_C = 875$ to 976 K and optimum
 Cesium gap 0.152 mm (2 cm^2), 0.203 mm (4 cm^2); $T_R = 582$ to 612 K and optimum
 Geometry cylindric; two with 2-cm^2 emitters, three with 4-cm^2 emitter
 Output 10.3 W/cm^2 at $T_E = 1800$ K for 2 cm^2 , 4.25 W/cm^2 at 1673 K for 4 cm^2

88. Bliaux, J.; Marquer, P.; Dumas, P.; Leclerc, A.; Desmarest, C.; and Ducrocq, D.: In Pile Life Testing of Thermionic Converter Sirene 311, pp. 130-140.

Emitter F^-CVD W (100) on Mo (backed by enriched UO_2); $T_E = 1560^\circ$ C (out of core), 1601° C (in core)

Collector Nb, 1 percent Zr; $T_C = 632^\circ \text{C}$ (out of core)
 Cesium gap 0.2 mm; T_R optimum for Cs, C compound reservoir
 Geometry cylindric; 20 cm^2
 Output out of core, 5 W/cm^2 at 10 percent efficiency; in core, 4.6 W/cm^2 at 8.5 percent efficiency
 Lifetime 4740 hr in 6-MW reactor ($2 \times 10^{12} \text{ N/cm}^2$), 3800 hr with no degradation; test terminated by emitter shortout

89. Jester, A.; Holick, H.; Krapf, R.; and Zöller, R.: Thermionic Converter Development for ITR, pp. 141-144.

Emitter Mo (with and without UO_2 backing); $T_E = 1400^\circ$ to 1700°C
 Collector $T_C = 600^\circ$ to 700°C
 Cesium gap $T_R = 350^\circ$ to 370°C and optimum
 Output and lifetime in-core test: UO_2 fueled emitter at 1400° to 1500°C , collector at 600° to 700°C , and reservoir at 350°C gave 3.5 to 5 W/cm^2 at 0.5 to 0.6 V for 3750 hr; out-of-core tests: as shown in the following table (from ref. 89):

OUT-OF-CORE TESTS^a

Diode	Emitter material	Emitter dimensions, mm		Collector material	Metal, ceramic seal	Life time, hr	Remarks
		Diameter	Length				
1	Sintered Mo	16	40	Sintered Mo	E2: Mo, Mn	300	Ceramic destroyed by cesium attack; shrinking of emitter diameter 0.1 mm
2	Sintered Mo	16	40	Sintered Mo	E2: Mo, Mn	300	Operated as vacuum diode; shrinking of emitter diameter 0.1 mm
3	Arc cast Mo	16	40	Sintered Mo	E37: Mo, Mn	1 100	Leak in metal, ceramic seal
4	Arc cast Mo	16	40	Sintered Mo	E37: Mo, Mn	^b >16 000	Still operating
5	Arc cast Mo	20	54	Sintered Mo	E37: tungsten metallizing	>7 000	Still operating; dimensions of electrodes as proposed for ITR
6	Arc cast Mo	16	40	Sintered Mo	E37: tungsten metallizing	>4 000	Still operating; emitter fueled with UO_2 powder
7	Arc cast Mo	20	54	Sintered Mo	E37: tungsten metallizing	>4 000	Still operating; dimensions of electrodes and metal ceramic seal for ITR

^aAll diodes 4 to 5 W/cm^2 at T_E 's from 1650° to 1700°C and T_R optimums from 360° to 370°C - except six in which "electrical output was high and the optimum cesium temperature was low," "attributed to excess oxygen diffusing through the emitter . . ."

^bValid for electrodes and metal, ceramic seal; cesium reservoir replaced after 3000 hr because of a leak.

90. Ernst, D. M.: Life Test Results from Cylindrical Diodes with Tungsten Emitters, pp. 146-149.

Emitter F⁻CVD W (100) (1) as-deposited, (2) etched as-deposited, (3) as-ground, (4) etched as-ground
 Collector Nb; T_C optimum
 Cesium gap 0.254 mm; T_R optimum
 Geometry cylindric, 1.27-cm diameter, 15 cm²
 Output for 50 W/cm² input and 8 A/cm²: (1) 4.7 W/cm², (2) 5.1 W/cm², (3) 4.4 W/cm², (4) 4.5 W/cm²; see ref. 72
 Lifetime (1) 6550 hr, (2) 6200 hr, (3) 5850 hr, (4) 5250 hr

91. Stapfer, Gerhard: Thermionic Converter Life-Test Program, pp. 150-156.

Emitter Re; T_E = 1800, 1900, 2000 K
 Collector Mo, Re; T_C near optimum (radiation cooled)
 Cesium gap T_R optimum
 Geometry 10 plane SET diodes
 Output as shown in the following table (from ref. 91):

Converter life-test performance

Converter	Design, T _E , K	Operating, T _E , K	Electrode material	Collector area, cm ²	Average, P _{OUT} , W/cm ²	E _{OUT} , v	Efficiency, percent	Thermal cycles	Operating time, hr	Failure mode
SN-101	2000	2000	Re, Re	1.88	25.0	0.7	10.0	195	20 700	Operating
SN-103	2000	2000	Re, Mo	1.88	21.0/10.0	0.7/0.5	9.0/5.5	15	7 168	Open circuit
SN-108	1900	2000	Re, Re	1.88	18.0	.7	7.7	0	1 247	Open circuit
T-VIII-7	2000	2000	Re, Mo	2.0	17.0	.7	7.5	10	8 326	Operating
T-VIII-12	2000	2000	Re, Mo	2.0	17.0	.7	7.5	9	6 421	Operating
T-VIII-16	2000	2000	Re, Mo	2.0	16.0	.7	7.0	14	8 100	Operating
TE-206	2000	2000	Re, Re	2.0	7.0	.7	4.0	7	11 470	Operating
VIII-S-23	2000	2000	Re, Mo	2.0	12.1	.7	6.9	2	740	Discontinued
VIII-S-20	2000	1800	Re, Mo	2.0	6.6	.7	5.0	2	2 944	Discontinued
VIII-S-9	2000	1900	Re, Mo	2.0	9.8	.7	5.5	8	1 200	Discontinued

92. Kascak, Thomas J.; Williams, Richard M.; and Kroeger, Erich W.: The Performance of a Molybdenum, Molybdenum Cylindrical Thermionic Converter, pp. 157-162.

Emitter Mo; $T_E = 1500$ to 1750 K
 Collector Mo; $T_C = 873$ to 1063 K
 Cesium gap 0.254 mm; $T_R = 515$ to 555 K
 Geometry cylindric; 1.27 -mm diameter, 15.2 cm²
 Output as shown in the following table (from ref. 92):

DIODE OUTPUT FOR MAXIMUM EFFICIENCY AND MAXIMUM
POWER DENSITY CONDITIONS

Emitter temperature, K	At maximum efficiency			At maximum power density		
	Electrode efficiency, percent	Electrode voltage, v	Power density, W/cm ²	Electrode efficiency, percent	Electrode voltage, v	Power density, W/cm ²
1500	2.1	0.12	0.6	2.0	0.09	0.7
1600	5.3	.26	1.8	4.9	.20	2.0
1750	8.4	.46	3.3	7.9	.36	3.6

93. Wilkins, D. R.; Wurm, J. P.; Derby, S. L.; and McCandless, R. J.: A Theoretical Study of Methods for Improving Thermionic Converter Performance, pp. 198-205.

Emitter polycrystalline W; $T_E = 1640$ to 1950 K
 Collector polycrystalline Mo; $T_C = 840$ to 910 K
 Cesium gap 0.152 to 0.508 mm; $T_R = 571$ to 635 K
 Geometry plane
 Output SIMCON correlation and performance maps

94. Rufeh, Firvoz; and Lieb, David: The Dependence of the Volt-Ampere Characteristics on Collector Temperature, pp. 237-246.

Emitter Cl⁻CVD W (110) (on F⁻CVD W (100)); $T_E = 1800, 1500, >>1300$ K
 Collector Mo; $T_C = 605$ to 1022 K
 Cesium gap 0.013 to 0.635 mm; $T_R = 461$ to 620 K
 Geometry plane, guarded
 Output study of collector effects on diode voltage (work function) and current (back emission) indicates that present theories are not adequate

95. Peelgren, M. L.; and Ernst, D.: Thermionic Diode Kinetics Experiment - Design and Startup, pp. 434-443.

Emitter Re; $T_E = 1850^\circ \text{C}$ maximum, 1800°C average
 Collector Mo; $T_C = 700^\circ \text{C}$
 Geometry four cylindric diodes, each 30 cm^2
 Output nominally 8.4 W/cm^2 at 0.6 V and 12 percent efficiency

96. Imbert, F.; and Shroff, A. M.: Thermionic Integrated Cesium Reservoir Module, pp. 528-534.

Emitter CVD W; $T_E = 1370^\circ$ to 1790°C
 Collector Mo; T_C optimum
 Cesium gap 0.2 mm ; T_R from Cs, C reservoir coupled to collector (T_C optimums occur within 50°C around 700°C)
 Geometry cylindric
 Output over 10 percent efficiency
 Lifetime 1000 hr and continuing

Conference Record of the Thermionic Conversion Specialist Conference. IEEE, 1970.

97. Dunlay, J.; and Meyers, R.: Emitter and Collector Sublimed Coatings, pp. 86-89.

Emitter PVD W (110) (on F⁻CVD W (100)); $T_E = (1) 1700 \text{ K}$, (2) 1800 K , (3) 1900 K
 Collector Nb; T_C optimum
 Cesium gap 0.254 mm ; T_R optimum
 Geometry plane
 Output at 10 A/cm^2 (1) 4.3 W/cm^2 , (2) 5.7 W/cm^2 , (3) 7.0 W/cm^2 , which equal outputs for single-crystal 110 W

98. Kuznetsov, V. A.: In-Pile Tests of Multielement Thermionic Converters with Molybdenum - and Tungsten - Based Cathodes, pp. 196-202.

Emitter Mo; "Mo-based alloy"; "W-based alloy"; "W, Re"; $T_E = 1300^\circ$ to 1700°C
 Collector Nb; $T_C = 600^\circ$ to 700°C
 Cesium gap 0.4 to 0.5 mm ; 2 to 19 torr
 Geometry multielement assemblies; five or six axially alined diodes with cylindric emitters, each having a plane active end
 Output and lifetime as shown in the following table (from ref. 98):

Converter number	Number of elements	Cathode can material	Cathode temperature, °C	Electric power density, W/cm ²	Time of in-pile experiment, hr
TIC-21	5	Molybdenum-based alloy	1600	^a 1.8 to 2.2	2750 ^b (2200)
TIC-28	5	Molybdenum monocrystal	1600	2.7	1400 ^b (1100) Experiment is continued
TIC-20	5	Tungsten-based alloy	1850 to 1900	7.8	900 ^b (650)
ES-6-1	6	Tungsten, rhenium	1850	6 to 7	75
ES-6-2	6	Tungsten, rhenium	1950	10	220

^aEfficiency, 9+ percent.

^bTime of maximum electric-power operation.

99. Rufeh, F.; Gunther, B.; and Lieb, D.: Collector Work Function Measurements, pp. 233-242.

Emitter $T_E = 575$ to 1800 K
Collector Mo; Nb; $T_C = 670$ to 775 K, $T_C/T_R = 1.1$ to 2.5
Cesium gap 0.013 to 1.016 mm; $T_R = 428$ to 516 K, $T_R/T_C = 0.4$ to 0.91
Output collector effects on diode performance (see ref. 94); present theories still fail to predict collector influences on outputs

100. Hansen, Lorin K.: Non-Saturation Phenomena in Thermionic Converters, pp. 305-311.

Emitter single-crystal 110 Mo; $T_E = 1600, 1682$ K
Collector single-crystal 110 Mo; $T_C = 850$ K
Cesium gap 0.127 to 1.27 mm; $T_R = 500$ to 580 K
Geometry plane, guarded
Output 1.7 W/cm² at 0.65 V, $T_E = 1682$ K, $T_C = 850$ K, $T_R = 548$ K

101. Rouklove, Peter: Radioisotope Thermionic Generator (RTIG), pp. 382-387.

Emitter Re; $T_E = 1573$ to 1773 K
Collector Nb; $T_C = 951$ K for 0.5 V
Cesium gap 0.762 mm (hot); $T_R = 594$ to 595 K for 0.5 V
Geometry cylindric; 4 cm²
Output at 1673 K design point 3.5 to 4.4 W/cm² at 0.5 V, 4.2 to 4.6 W/cm² at 0.4 V; at 10 A/cm² outputs were as follows:

T_E , K	1573	1673	1713	1773
W/cm^2	3.3	4.2	4.8	5.2

102. Gunther, B.: Emitter Temperature Dependence of Lower Mode Current, pp. 446-452.

Emitter 110, Cl^-CVD (110); F^-CVD (100) W; $T_E = 1600$ to 1850 K
Collector Nb; $T_C = 760$ to 930 K
Cesium gap 0.054 to 0.508 mm; $T_R = 530$ to 660 K
Geometry plane, guarded; 2 cm^2
Output apparent lower-mode saturation currents (at or near ignition);
limited by electronic space charge and by collisions; used to determine emitter temperatures (for in-core diodes)

103. Gronroos, H. G.; and Sawyer, C. D.: Reactor Simulator Runs with Thermionic Diode Kinetics Experiment, pp. 453-461.

Emitter Re; $T_E = 1300^0$ to 1700^0 C
Collector Nb; T_R not optimum
Cesium gap 0.254 mm; $T_R = 293^0$ C (near optimum initially)
Geometry cylindric; 1.9 -cm diameter, 5.08 cm long
Output 3.3 W/cm^2 at 0.5 V, $T_E = 1700^0$ C (not optimum, used for kinetics input to reactor simulator)

104. Rufeh, F.; and Lieb, D.: Thermionic Performance of Fluoride CVD Tungsten-Niobium Converter, pp. 462-470.

Emitter F^-CVD W (100) (compared with Cl^-CVD W (110), Mo; single-crystal 110 W, Nb; or single-crystal-110 W, Mo, O_2 diode);
 $T_E = 1600$ to 2000 K
Collector Nb (Mo or Nb); $T_C = 670$ to 1010 K
Cesium gap 0.013 to 1.03 mm; $T_R = 480$ to 655 K
Additive O_2 in the single-crystal 110 W, Mo diode
Geometry plane, guarded; 2 cm^2
Output I, V performance maps for F^-CVD -W, Nb diode; at $T_E = 1800$ K, 0.254 mm spacing, 10 A/cm^2 output was as follows:

Diode	F^-CVD -W, Nb	Cl^-CVD -W, Mo	1-xtal-110-W, Nb	1-xtal-110-W, Mo, O_2
W/cm^2	2.7	4.8	5.8	7.6

105. Lieb, D.; and Rufeh, F.: Thermionic Performance of CVD Tungsten Emitters with Several Collector Materials, pp. 471-480.

Emitter Cl⁻CVD W (110); F⁻CVD W (100); single-crystal 110 W;
 $T_E = 1600$ to 2000 K
Collector Mo (polycrystalline or PVD (110)) or Nb; $T_C = 970$ to 1023 K
Cesium gap 0.025 to 2.032 mm; $T_R = 539$ to 653 K
Additive O₂ in single-crystal 110 W, Mo diode
Output good I, V curves for Cl⁻CVD W, Nb; from 1700 to 1900 K with 0.254 mm spacing and 10 A/cm² output was as follows:

Diode	1-xtal-110 W, Mo, O ₂	1-xtal-110 W, Nb	Cl ⁻ CVD W, Mo	F ⁻ CVD W, Nb
W/cm ²	5.8 to 9.0	4.5 to 7.0	4.0 to 6.3	1.7 to 3.7

106. Samstad, G. I.; Danko, J. C.; and Levin, H. A.: Performance of Cylindrical Converter with Deep Etched Tungsten Emitter, pp. 481-486.

Emitter Electroetched F⁻CVD W (110) (compared with both Cl⁻CVD (110) and F⁻CVD (100) W); $T_E = 1400^\circ$, 1500° , 1700° C
Collector Nb; $T_C = 600^\circ$, 800° , 950° , 1000° C
Cesium gap 0.3 mm; $T_R = 320^\circ$ to 377° C
Geometry cylindric; 1.41 -cm diameter, 11 cm²
Output 3.2 to 7.6 W/cm² for 1400° to 1700° C with T_R optimum and T_C near optimum at 10 A/cm²; performance curves and comparisons; electroetched F⁻CVD W (110) gave outputs comparable with those for Cl⁻CVD W (110)
Lifetime output was stable for 5000 hr at 1700° C

107. Lancashire, Richard B.: Computer-Acquired Performance Map of an Etched-Rhenium, Niobium Planar Diode, pp. 487-491.

Emitter etched Re; $T_E = 1550$ to 2050 K
Collector Nb; $T_C = 750$ to 1180 K
Cesium gap 0.254 mm; $T_R = 525$ to 650 K
Geometry plane, guarded
Output maximum efficiencies, 7.3 to 16 percent from 1600 to 2000 K; at 10 A/cm² with T_C and T_R optimum output was as follows:

T_E , K	1600	1700	1800	1900	2000
W/cm^2	2.1	4.1	5.7	7.8	9.1

108. Ernst, Donald M.: Thermionic Performance of CVD Chloride Tungsten and Sublimed Coated Molybdenum Electrodes in Cylindrical Heat Pipe Diodes, pp. 492-497.

Emitter Cl^-CVD W (110); $T_E = 1600$ to 1900 K
Collector PVD Mo (110); $T_C = 292^\circ$ to 640° C
Cesium gap 0.254 mm; $T_R = 245^\circ$ to 305° C
Geometry five cylindric diodes, each 1.9 -cm diameter and 20 cm^2
Output at 10 A/cm^2 with T_C and T_R optimum output was as follows:

T_E , K	1600	1700	1800	1900
W/cm^2	3.2	5.3	7.4	9.2

this high performance was stable through 100 hr of initial testing

109. Yates, M. K.; Fitzpatrick, G. O.; and Kay, J., Jr.: Long Term Operation of Out-of-Pile Thermionic Converters, pp. 498-507.

Emitter (1) Cl^-CVD W (110) (standard Cs reservoir), (2) F^-CVD W (100) (graphite, Cs reservoir); (1) $T_E = 1700^\circ$ C, (2) $T_C = 1760^\circ$ C
Collector Nb; (1) $T_C = 799^\circ$ C, (2) 701° C
Cesium gap (1) 0.229 mm, (2) 0.203 mm; (1) $T_R = 352^\circ$ C, (2) 814° C (C, Cs reservoir)
Geometry cylindric (1) 2.54 cm long, 16.1 cm^2 ; (2) cylindric, 5.08 cm long, 26.7 cm^2
Output (1) 8.0 W/cm^2 at 14 percent efficiency, (2) 6.8 W/cm^2 at 12 percent efficiency

110. Shroff, A. M.; and Imbert, F.: Integrated Cesium Reservoir Thermionic Converter for In-Pile Applications, pp. 508-512.

Emitter W (apparently)
Collector Mo (apparently); $T_C \approx 650$ K
Cesium gap 0.2 mm (apparently); T_R near T_C for Cs, C reservoir
Output maximum experimental value, 6.2 W/cm^2

111. Knauss, G.: A Longlife Thermionic Diode with Barium and Cesium Vapors, pp. 513-516.

Emitter polycrystalline W; $T_E = 1800, 1900, 1950$ K
 Collector Ta; $T_C = 920$ to 1120 K
 Cesium gap 0.1 to 2.5 mm; $T_R = 390$ to 473 K, $P_{Cs} = 0$
 Additive Ba; $T_{Ba} = 900$ to 1100 K
 Geometry plane
 Output several I, V figures; at $T_E = 1900$ K, $T_C = 1120$ K, $T_{Ba} = 1100$ K, $T_{Cs} = 473$ K maximum outputs occurred at 0.1 mm spacing; for these conditions, 8.5 W/cm² at 13 A/cm² was approximate maximum

112. Schock, A.; Raab, B.; and Giorgio, F.: Design, Fabrication, and Testing of a Full-Length External-Fuel Thermionic Converter, pp. 517-532.

Emitter W (backed with enriched UO₂); $T_E \approx 1900$ to 2100 K
 Collector Nb; T_C optimum
 Cesium gap 0.254 mm; T_R optimum
 Additive U and O possible
 Geometry cylindric; 1.27 -cm diameter, 20.32 cm long
 Output 7.1 W/cm² (9.8 A/cm²) at 11.5 percent efficiency with $T_E = 1940$ K, $T_R = 531$ K

113. Ernst, D. M.: Design, Fabrication and Testing of Externally Configured Thermionic Diodes, pp. 533-538.

Emitter F⁻CVD W (100); $T_E = 1800$ to 2070 K
 Collector Mo; $T_C = 675^\circ$ to 845° C
 Cesium gap 0.254 mm; $T_R = 290^\circ$ to 333° C
 Geometry cylindric; 1.14 -cm diameter, 84 cm²
 Output 4.1 to 6.2 W/cm² at 6 A/cm², $T_E = 1900$ to 2070 K

114. Teagan, W. Peter: The Development of Thermionic Diodes for Isotope-Fueled Generators, pp. 539-545.

Emitter etched Re (compared with 0001 Re with and without O₂); $T_E = 1600^\circ$ C
 Collector Mo; $T_C = 600^\circ$ C
 Cesium gap 0.127 mm; T_R optimum
 Additive O₂ with 0001 Re
 Geometry plane; 13.3 cm²

Output	4.5 W/cm ² (0.9 V) to 9.6 W/cm ² (0.4 V); maximum electrode efficiency of 15 percent with 7.9 W/cm ² at 0.7 V (0001 Re at 1900 K with T _R optimum and 0.254-mm spacing produced 11.9 W/cm ² and with O ₂ 17.5 W/cm ² both at 0.7 V, 8.8 W/cm ² and with O ₂ 10.3 W/cm ² both at 10. A/cm ²)
Lifetime	3000 hr at maximum-electrode-efficiency point with no change

115. Kroeger, Erich W.: Fabrication and Evaluation of an Out-of-Core Thermionic Converter Module, pp. 546-549.

Emitter	Cl ⁻ CVD Re; T _E = 1600 to 1700 K
Collector	Nb, 1 percent Zr
Cesium gap	0.229 mm
Geometry	cylindric; 10.16 cm long, 73.7 cm ²
Output	better than that for a polycrystalline-Re, Nb diode

116. Clémot, M.; Gayté, B.; and Lebourg, R.: Post Test Examinations of a Long Life Thermionic Converter, pp. 556-561.

Emitter	CVD W; T _E = 1820 K
Collector	Mo; T _C = 840 K
Cesium gap	0.2 mm; T _R = 575 K
Geometry	cylindric; 20 cm ²
Output	7.5 W/cm ² at 12.5 percent efficiency
Lifetime	Emitter, collector short circuit after 9000 hr. "In any case, the failure was accelerated by material transport from the emitter to the molybdenum collector. This may be avoided by using converters with Nb, 1 percent Zr collectors gettering O ₂ present in the interelectrode spacing."

Conference Record of the Thermionic Conversion Specialist Conference. IEEE. 1971.

117. Yates, M. K.; Holland, J. W.; Allen, D. T.; Fitzpatrick, G. O.; Grebetz, J. C.; and Horner, M. H.: Thermionic Fuel Element Development Program Status, pp. 68-77.

Emitter	Cl ⁻ CVD W (110); T _E = 1500°, 1600° C
Collector	Nb; T _C optimum
Cesium gap	T _R optimum
Additive	U and O or C possible
Geometry	cylindric TFE's
Output	as shown in the following table (from ref. 117):

TFE TEST HISTORY

	TFE 2E1	TFE 2E2	TFE 2E3	TFE 6F1	TFE 1F1	TFE 1F2
Emitter	W (110)	W (110)	W (110)	W (110)	W (110)	W (110)
Collector	Nb	Nb	Nb	Nb	Nb	Nb
Fuel	UO ₂	UO ₂	UC, ZrC	UC, ZrC	UO ₂	UC
Number of cells	2	2	2	6	1	1
Test duration, hr	^a 9700	^a 200	3661	^a 1000	^a 200	^a 1000
Average electrode power density, W/cm ²	5	6	3	2	4	4
Average emitter temperature, °C	1600	1600	1500	1600	1500	1600
Failure mode	(a)	(a)	Envelope leak	(a)	(a)	(a)

^aStill in operation 9/71.

118. Shimada, K.; and Rouklove, P.: Reactor Core Length, Externally Configured Thermionic Converter, pp. 110-115.

Emitter F⁻CVD W (100); T_E = 1638 to 1942 K
Collector Mo; T_C = 885 to 945 K
Cesium gap T_R = 565 to 633 K
Geometry cylindric; 1.14-cm diameter, 91.2 cm²
Output 1.95 W/cm² with 5.5 percent efficiency at T_E = 1942 K,
T_C = 900 K, T_R = 633 K

119. Schock, A.; and Raab, B.: Development of a Full-Length External-Fuel Thermionic Converter for In-Pile Testing, pp. 116-127.

Emitter W, 2 percent ThO₂ (enriched UO₂ backed in core, not here);
T_E = 1650° to 1700° C
Collector T_C optimum
Cesium gap 0.254 mm; T_R = 380 to 540 K
Additive Th and O
Geometry cylindric; 20.3 cm long, 74.7 cm²
Output 7.1 W/cm² with 11.5 percent efficiency out of core at
T_E = 1940 K, T_R = 531 K
Lifetime removed after 1100 hr

120. Henne, R.: Thermionic Energy Conversion with a Ba-Cs-Diode, pp. 212-219.

Emitter Mo; T_E = 1870 to 2000 K
Collector Mo; T_C = 950° to 1150° C
Cesium gap 0.05 to 2.0 mm; T_R = 120° to 300° C

Additive Ba; $T_{Ba} = 450$ to 950 K
 Geometry plane, guarded
 Output maximum indicated, 6 W/cm^2 at 1.0 V , 0.1 mm spacing,
 $T_E = 2000 \text{ K}$, $T_C = 1220 \text{ K}$, $T_{Ba} = 950 \text{ K}$, $T_R = 450 \text{ K}$

121. Wilson, V. C.: Output Performance of a Thermionic Converter with an Oriented Tungsten (110) Emitter and a Polycrystalline Tungsten Collector, pp. 220-224.

Emitter $\text{Cl}^- \text{TVDW (110)}$ (thermally vapor-deposited); $T_E = 1673, 1865, 2057 \text{ K}$
 Collector polycrystalline W; Nb; Ni; $T_C = 858$ to 1073 K and optimum
 Cesium gap 0.051 to 0.508 mm ; $T_R = 348$ to 453 K and optimum
 Geometry plane, guarded
 Output good performance comparison; at 10 A/cm^2 , T_C and T_R optimum
 the output was as follows:

Collector	$T_E, \text{ K}$					
	1673		1865		2057	
	Volts	Ratio	Volts	Ratio	Volts	Ratio
Nb	0.39	1.00	0.73	1.00	1.03	1.00
W	.45	1.15	.78	1.07	1.12	1.09
Ni	.41	1.05	.85	1.16	1.22	1.18

122. Manista, E. J.; Smith, A. L.; and Lancashire, R. B.: Comparison of Computer-Acquired Performance Data from Several Fixed Space Planar Diodes, pp. 225-230.

Emitter etched Re; $\text{Cl}^- \text{CVD W (110)}$; PVD W; $T_E = 1500$ to 2000 K
 Collector Mo; Nb; $T_C = 750$ to 1100 K
 Cesium gap 0.254 mm ; $T_R = 520$ to 650 K
 Geometry plane, guarded
 Output voltages at 10 A/cm^2 with T_R and T_C optimum were as follows:

Diode	$T_E, \text{ K}$			
	1700	1800	1900	2000
	Voltage, V			
Re, Nb	0.43	0.60	0.77	0.93
CVD-W, Nb	.35	.51	.60	.74
Re, Mo	.33	.43	.53	.66
PVD-W, Nb	.30	.36	.50	.66

123. Ruffe, F.; Gunther, B.; and Lieb, D.: Performance Comparison of Thermionic Converters with Several Collector Materials, pp. 231-240.

Emitter $\text{Cl}^- \text{CVD W (110)}$; $T_E = 1600$ to 2000 K
 Collector PVD Mo; Nb; W; single-crystal 110 W; $T_C = 620$ to 1020 K
 Cesium gap 0.127 to 1.016 mm; $T_R = 517$ to 647 K
 Additive special care to minimize O_2 effects
 Geometry plane, guarded
 Output 5.1 to 7.8 W/cm^2 with single-crystal-110-W collector and approximately 3.9 to 6.2 W/cm^2 with each of the other collectors, all for 0.254 mm spacing, 10 A/cm^2 , $T_E = 1700$ to 1900 K; excellent performance maps

124. Dunlay, J.; Matsuda, S.; and Poirier, V.: Cylindrical Diode Characteristics with Sublimed Electrode Surfaces, pp. 242-247.

Emitter PVD W (compared with $\text{Cl}^- \text{CVD W}$ and $\text{F}^- \text{CVD W}$); $T_E = 1600$ to 1900 K
 Collector PVD Mo (with MoO_2 and MoO_3)
 Cesium gap 0.508 mm; $T_R = 250^\circ$ to 300° C
 Additive O with PVD-Mo collector
 Geometry cylindric, cup-shaped; 37 cm^2
 Output outputs limited to 7 A/cm^2 by test facility; at 6 A/cm^2 , 0.508 mm spacing, $T_E = 1600$ to 1900 K the output was as follows:

Diode	W/cm^2
PVD-W, PVD-Mo	2.3 to 6.2
$\text{Cl}^- \text{CVD-W, Nb}$	2.1 to 3.8
$\text{F}^- \text{CVD-W, Nb}$	0.6 to 2.1

125. Shimada, K.: Out-of-Core Evaluations of a Nonfueled and a UO_2 -Fueled Cylindrical Thermionic Converter, pp. 248-252.

Emitter etched Re (with and without UO_2 backing); $T_E = 1700$ to 2000 K
 Collector PVD Mo; T_C optimum (until heater failed)
 Cesium gap 0.203 mm; T_R optimum
 Additive U and O (both definitely diffused through the emitter at 1900 to 2000 K)

Geometry cylindric, 1.27-cm diameter, 15.2 cm²
 Output 6.5 W/cm² at 0.9 V with 11 percent efficiency for fueled diode, which was quite inferior to nonfueled one
 Lifetime during 2400 hr at 2000 K fueled diode lost 15 percent in output current; nonfueled one showed no change after 4000 hr

126. Shimada, K.; and Cassell, P. L.: Evaluations of Uranium-Nitride Fueled Converters, pp. 253-257.

Emitter Re; W (each UN backed); T_E = 1660 to 2000 K
 Collector Nb; T_C = 806, 840 K, optimum
 Cesium gap 0.25 mm; T_R = 555 to 622 K and optimum
 Additive U and N possible
 Geometry plane; 1.82 cm²
 Output at 10 A/cm² the output was as follows:

Emitter	T _E , K	
	1800	2000
	W/cm ²	
Re	5.7	8.0
W	1.2	3.2

127. Haar, W.; and Holick, H.: Parametric Optimization of a Cylindrical Converter with a Molybdenum Emitter and Niobium Collector, pp. 258-263.

Emitter Mo; T_E = 1550 to 2000 K
 Collector Nb, 1 percent Zr; T_C = 750 to 1020 K
 Cesium gap 0.16 mm; T_R = 580 to 670 K
 Geometry cylindric; 2-cm diameter, 34 cm²
 Output optimums from 1550 to 2000 K, 0.8 to 6.5 W/cm²; 3.4 to 12 percent efficiencies

128. Razor, N. S.; and Britt, E. J.: Suppression of Arc Drop in Thermionic Converters, pp. 272-281.

Emitter CVD W; T_E = 1890 K
 Collector Mo
 Cesium gap 0.013 to 0.508 mm; 4 torr
 Geometry plane
 Output performance characteristics of an Ar diode (mixed-oxide emitter, Cu collector) contribute to understanding Cs counterparts

129. McCandless, R. J.; and Wilkins, D. R.: Computed Performance Data for a Thermionic Converter Having a Cl-CVD-W Emitter and a Polycrystalline Nb Collector, pp. 282-287.

Emitter Cl-CVD W (110); $T_E = 1600$ to 2200 K
Collector Nb; $T_C = 800$ to 1200 K
Cesium gap 0.254 to 0.381 mm; $T_R = 540$ to 653 K
Geometry based on data from a plane, guarded diode
Output SIMCON correlation of V. C. Wilson results; for 10 A/cm^2 and 0.254 mm spacing the output was as follows:

T_E , K	1651	1843	2035
T_C , K	948	998	1073
T_R , K	573	600	625
W/cm^2	4.0	7.0	9.5

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 16, 1972,
503-25.



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